PALACKY UNIVERSITY
IN OLOMOUC
FACULTY OF SCIENCE
DEPARTMENT OF GEOLOGY

Application of seismic methods for geological exploration

Bachelor thesis

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Petroleum Engineering (B0724A330002)
Fulltime study

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Annotate:

Seismic methods are a powerful tool for geological exploration, as they allow researchers to investigate subsurface structures and identify potential oil and gas reservoirs, mineral deposits, and groundwater resources. seismic methods are applied in geological exploration for example Mapping subsurface structures: Seismic waves can be used to create images of the subsurface by bouncing sound waves off different layers of rock and measuring the time it takes for the waves to return to the surface. This technique, known as seismic reflection, is used to create 2D and 3D maps of subsurface structures, including faults, folds, and sedimentary layers, to Identify oil and gas reservoirs: Seismic reflection can also be used to identify potential oil and gas reservoirs. seismic methods are a valuable tool for geological exploration, providing a non-invasive way to investigate subsurface structures and identify potential resources. Seismic methods are non-invasive, meaning that they do not require drilling or excavation to investigate subsurface structures. This can save time and money compared to other exploration methods, also it has High-resolution imaging, which can produce high-resolution images of subsurface structures, which can provide valuable information for geological exploration and engineering applications. seismic methods have significant advantages for geological exploration and engineering applications, but there are also some disadvantages that need to be considered when using these methods, however, Seismic methods can have a negative impact on the environment, particularly marine life. Seismic air guns, which are commonly used in offshore exploration, can produce loud underwater noises that can harm or disrupt marine animals, this thesis shows the knowledge that is necessary for a geologist to know, help them in their job of exploration and Identify the structure of the earth boundaries and this thesis is showing an example of seismic survey and data interpretation, the methods that been used is a land seismic survey and it's been done in Kosice city which is located in Slovakia. It shows The East-Slovakian Basin is a basin with complex tectonic history determined by the oblique subduction of an oceanic slab occurring between the North-European Platform and the

ALCAPA (Alpine-Carpathian-Pannonian) plate. The requirement tools that had been used in this seismic operation consisted ammeter (seismic source), receiver (hydrophones, geophones), and seismograph device (Seismograph ABEM Terraloc) is a standalone system and comes with a built-in computer, data storage, and measurement channels, and user interface. Measurements are conducted using a graphical interface with a look and feel that is familiar. in order to get information about Kosice structure boundaries. Six seismic sections were analyzed in order to find the basic geologic and tectonic structure of the Kosice depression, which is a part of the East-Slovakian Neogene Basin. the result of the seismic interpretations some of the seismic sections of Kosice have low amplitude and high frequency. The reflectors are discontinuous, some others have low amplitude and low frequency, and mplitude and the reflectors are continuity, high frequency, and amplitude.

Komentovat:

Seismické metody jsou mocným nástrojem pro geologický průzkum, protože umožňují výzkumníkům zkoumat podpovrchové struktury a identifikovat potenciální zásoby ropy a zemního plynu, ložiska nerostných surovin a zdroje podzemních vod. Seismické metody se používají v geologickém průzkumu, například Mapování podpovrchových struktur: Seismické vlny mohou být použity k vytvoření obrazů podpovrchových odrazem zvukových vln z různých vrstev horniny a měřením času potřebného k návratu vln na povrch. Tato technika, známá jako seismický odraz, se používá k vytvoření 2D a 3D map podpovrchových struktur, včetně zlomů, vrásů a sedimentárních vrstev, k identifikaci ložisek ropy a zemního plynu: Seismický odraz může být také použit k identifikaci potenciálních ložisek ropy a plynu. Seismické metody jsou neinvazivní, což znamená, že nevyžadují vrtání nebo výkop pro zkoumání podpovrchových struktur. To může ušetřit čas a peníze ve srovnání s jinými metodami průzkumu, také má zobrazování s vysokým rozlišením, které může produkovat obrazy podpovrchových struktur s vysokým rozlišením, které mohou poskytnout cenné informace pro geologický průzkum a inženýrské aplikace. Seismické metody mají významné výhody pro geologický průzkum a inženýrské aplikace, ale existují také některé nevýhody, které je třeba vzít v úvahu při použití těchto metod, avšak seismické metody mohou mít negativní dopad na životní prostředí, zejména na mořský život. . Seismické vzduchové zbraně, které se běžně používají při průzkumu na moři, mohou vytvářet hlasité podvodní zvuky, které mohou poškodit nebo narušit mořské živočichy, tato práce ukazuje znalosti, které jsou nezbytné pro geologa vědět, pomoci jim v jejich práci průzkumu a Identifikovat strukturu hranic Země a tato práce ukazuje příklad seismického průzkumu a interpretace dat, použitá metoda je pozemní seismický průzkum a byla provedena ve městě Košice, které se nachází na Slovensku. Východoslovenská pánev je pánev s komplexní tektonickou historií určenou šikmou subdukcí oceánské desky vyskytující se mezi Severoevropskou platformou a alpsko-karpatsko-panonskou deskou ALCAPA. Požadované nástroje, které byly použity v této seizmické operaci, se skládaly z ampérmetru (seismický zdroj), přijímače (hydrofony, geofony) a seismografického zařízení (Seismograph ABEM Terraloc) je samostatný systém a je dodáván s vestavěným počítačem, datovými a měřicími kanály a uživatelským rozhraním. Měření se provádí pomocí grafického rozhraní se vzhledem a chováním, které je důvěrně známé. za účelem získání informací o hranicích struktury Košic. Bylo analyzováno šest seismických úseků s cílem nalézt základní geologickou a tektonickou strukturu Košické deprese, která je součástí východoslovenské neogénní pánve. výsledek seismických interpretací: některé seismické úseky Košic mají nízkou amplitudu a vysokou frekvenci. Reflektory jsou nespojité, některé jiné mají nízkou amplitudu a nízkou frekvenci a mplitudu a reflektory jsou kontinuita, vysoká frekvence a amplituda.

Klíčová slova: seismický, metoda, průzkum, odraz, interpretace, vlastnosti odraz, seismické fyzikální vlastnosti, gravitační, frakční seismické, horniny, struktura, vlny seismická vlna, zemní plyn, technika, reflexní technika, fundamentální geologické, vědy o Zemi, změny zdrojů, průzkum uhlovodíků, vlny tělesa, povrchové vlny, seismické vlny, seismické zdroje, šíření, základní princip, Vlny lásky, Rayleighovy vlny, seismické průzkumy, Sparker, deska Boomer, kompresor, stohovaný, comer Frekvence, frekvenční odezva, pozemní rychlost, geofonní cívka, proudy, zvukové vlny, hydrofony.

Keywords: seismic, method, exploration, reflection, interpretation, properties Reflection, Seismic Physical Properties, gravitational, fraction seismic, rocks, structure, waves seismic wave, natural gas, technique, reflection technique, fundamental geological, Earth Sciences, sources change, hydrocarbon exploration, body waves, surface waves, seismic waves, seismic sources, spreading, basic principle, Love waves, Rayleigh waves, seismic surveys, Sparker, plate Boomer, compressor, comer frequency, frequency response, ground velocity, geophone coil, streamers, sound waves, hydrophones.

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I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

In Olomouc, May 27, 2022 ……………………………………………

Sarmad Rasheed

Acknowledgment

I would like to thank my family for supporting me, I want to thank my family for their moral support, the palacky university, my teachers, all its employees, and everyone who contributed to helping me move forward and to be what I am now. A word of thanks is not enough for them, they have all thanks and appreciation.

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List of abbreviations:

CDP	common-depth-point
NW	North-west
SE	South-East

Introduction

Geophysical exploration is focused on detecting changes in the physical properties or rocks such as gravitational acceleration, magnetic, electrostatic, resistivity, seismic wave speed etc. These properties are associated with geological conditions and their changes and may be directly or indirectly related to an economic mineral resource. We can also find their importance in many other both industrial and research sectors like mining and exploration exploring oil, water, and geothermal reservoirs and collecting data from the earth to explain basic scientific questions - Earth structure, tectonics, etc.). the geophysical methods bring knowledge on the subsurface structure without spending a long drilling line and taking samples to a laboratory to identify. The seismic method is critical in the search for hydrocarbons. It was introduced by Dr. Kärcher in Oklahoma in 1921. He showed that based on measuring time and other properties of seismic waves it is possible to find boundaries between rocks of different lithological properties. Since then, the reflection seismic is the main exploration tool for hydrocarbon companies around the world. The improved technologies, both for gathering seismic data, their processing, and, not at least, their interpretation, reach highly hesitated level reflected by either termly high resolution of this method. The high resolution together with 3D, or in some cases 4D visualization essentially simplify and economize the exploration process. Three fundamental steps of seismic exploration are data collection, processing, and interpretation. All of them determine the resolution of the method (see chapter 2). The thesis was assigned to me by the Dept. of Geology, Faculty of Science, Palacky University Olomouc, Czech Republic. The supervisor of the thesis is Prof. Ing. Juraj Janocko, Ph.D. The thesis includes a theoretical part and a case study showing the practical application of reflection seismic. The theoretical part explains the basics of the reflection seismic and the application of this method in the industry. The case study shows an interpretation of 2D seismic sections from the East-Slovakian Neogene Basin. The interpretation shows the basic features that are possible to derive from the reflection seismic method.

The main aim of my thesis is to show the advantage of the reflection seismic method for hydrocarbon exploration. It has several objectives:

1) To show the basic principles of reflection seismic.

2) To show the application of reflection seismic in different geological fields.

3) Introduce several examples of the application of seismic reflection method in different oil fields.

4) To show a study case demonstrating the application of the seismic reflection method.

1. Seismic survey

1.1Overview of seismic survey techniques

A seismic survey is a method of examining subsurface structures, particularly in the discovery of petroleum, natural gas, and mineral resources by using reflected and refracted waves for defining boundaries between rocks with different physical properties (mostly given by their density). the time approach is measured between the place that the seismic wave has been shoot (the location where the seismic source has been used) and receiver(geophones)had been set. The incoming signal is processed by different geophysical and mathematical methodologies resulting in the production of seismic sections displaying seismic lines – reflectors representing boundaries between rocks with different densities. The seismic sections are analyzed by seismic interpretation in order the model the subsurface geological structure in the analyzed area. The seismic methodology advanced a lot during the last few decades – the original "hand-made" interpretation of 2D seismic lines changed for the interpretation of 3D seismic cubes by sophisticated software (e.g. Petrel) and even by artificial intelligence.

The seismic survey is used for different scientific and industrial aims. For science, the refraction seismic has already been applied since the end of 19teen and the beginning of the

20-ty century when it appears as an effective tool for recognizing the basic structure of the Earth. The properties of P and S waves, generated by volcanic eruptions and, later, powerful bomb tests, were used for identifying solid and viscous layers of the Earth with implications for its structure. Based on this, the thickness of the solid mantle, liquid outer core, and solid inner core was estimated (see Fig. 1). Today, refraction seismic is a power full tool for indicating ancient subduction zones the thicknesses of earth's crust, the geometry of subducted crust segments, etc.

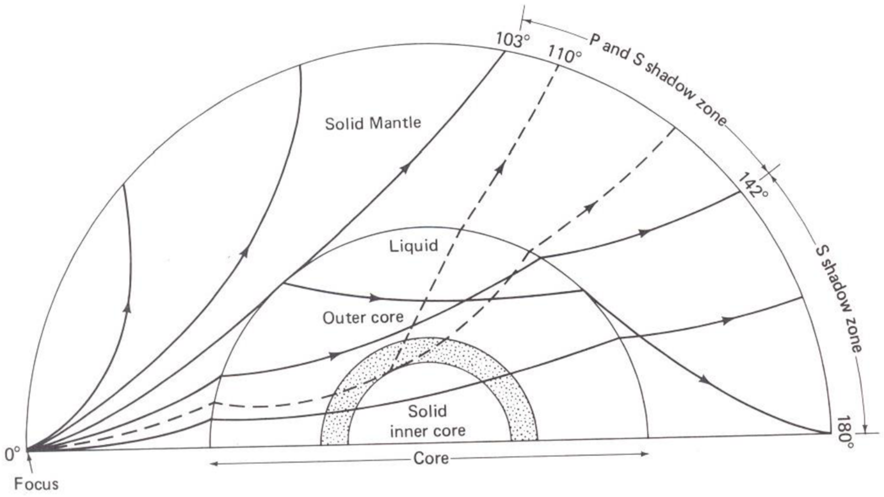
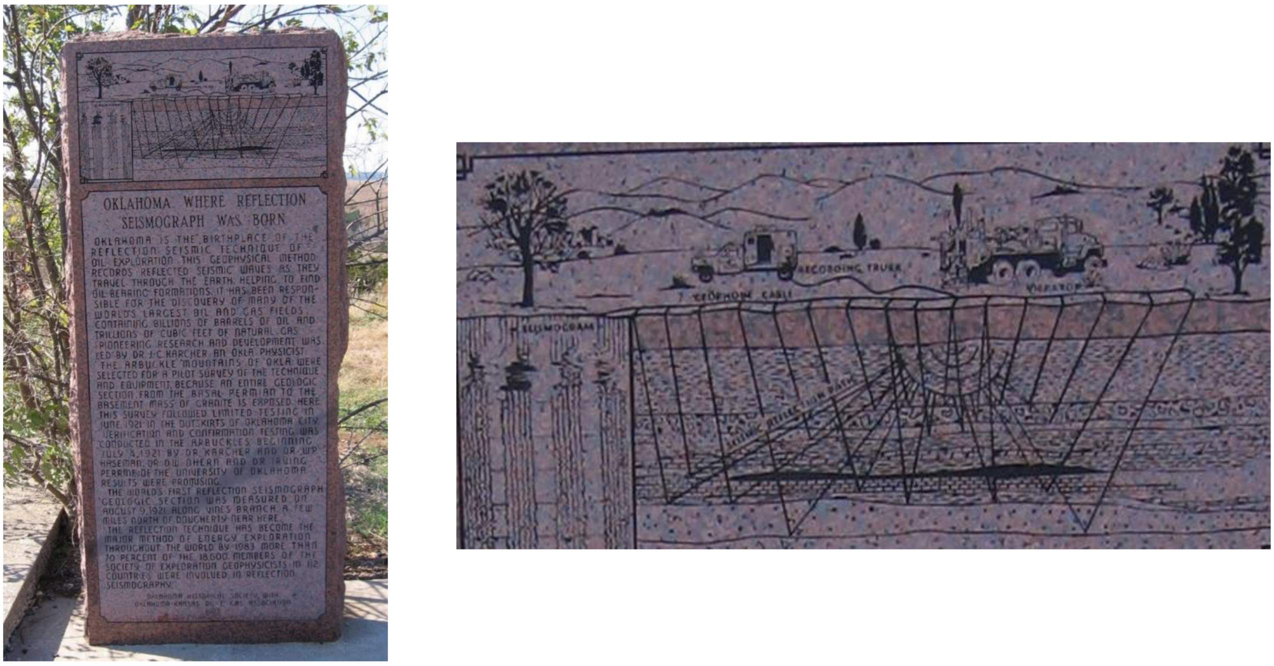


Figure 1 Selected ray paths for P-waves passing through the Earth. Such rays provide the principal evidence for the internal structure as shown. The P and S shadow zones are marked on the right. The dashed ray paths represent weak P waves within the shadow zones.

Even if the contribution of the seismic methods is immense for the scientific fields, the application of seismic methods for industry brought a fundamental change in hydrocarbon exploration all around the world. The reflection of seismic waves helped to discover a lot of the largest oil and gas fields that contain natural gas. This change significantly implied the direction of development of different industrial segments depending on fossil fuels.

The "Cradle" of the seismic reflection technique of oil exploration is located in Oklahoma, US, where the first reflection seismograph was constructed by Dr. J.C. Karcher (Fig. 2), an Oklahoma physicist. He selected the Arbuckle Mountains of Oklahoma for the first survey of the seismic reflection technique. This was selected because of the structure of the mountains with thick intervals of Permian rocks overlying granites providing a good difference between the physical properties of rocks. This survey had tested in June 1921 on the outskirts of Oklahoma City. Verification and confirmation testing were conducted in the Arbuckle beginning in July 1921. The results of these tests were promising. After this, the method of wave reflection had been the main method in the exploration process



OKLAHOMA WHERE REFLECTION
SEISMOGRAPH WAS BORN

OKLAHOMA IS THE BIRTHPLACE OF THE REFLECTION SEISMIC TECHNIQUE OF OIL EXPLORATION THIS GEOPHYSICAL METHOD RECORDS REFLECTED SEISMIC WAVES AS THEY TRAVEL THROUGH THE EARTH, HELPING TO FIND OIL-BEARING FORMATIONS. IT HAS BEEN RESPONSIBLE FOR THE DISCOVERY OF MANY OF THE WORLD'S LARGEST OIL AND GAS FIELDS, CONTAINING BILLIONS OF BARRELS OF OIL AND TRILLIONS OF CUBIC FEET OF NATURAL GAS.

PIONEERING RESEARCH AND DEVELOPMENT WAS LED BY DR. J.C. KARCHER AN OKLA PHYSICIST.

THE ARBUCKLE MOUNTAINS OF OKLA WERE SELECTED FOR A PILOT SURVEY OF THE TECHNIQUE AND EQUIPMENT, BECAUSE AN ENTIRE GEOLOGIC SECTION FROM THE BASAL PERMIAN TO THE BASEMENT MASS OF GRANITE IS EXPOSED HERE. THIS SURVEY FOLLOWED LIMITED TESTING IN JUNE, 1921 IN THE OUTSKIRTS OF OKLAHOMA CITY.

VERIFICATION AND CONFIRMATION TESTING WAS CONDUCTED IN THE ARBUCKLES BEGINNING JULY 4, 1921 BY DR. KARCHER AND DR. W.P. HASEMAN, DR. D.W. OHERN AND DR. IRVING PERRINE OF THE UNIVERSITY OF OKLAHOMA. RESULTS WERE PROMISING.

THE WORLD'S FIRST REFLECTION SEISMOGRAPH GEOLOGIC SECTION WAS MEASURED ON AUGUST 9, 1921 ALONG VINES BRANCH, A FEW MILES NORTH OF DOUGHERTY NEAR HERE.

THE REFLECTION TECHNIQUE HAS BECOME THE MAJOR METHOD OF ENERGY EXPLORATION THROUGHOUT THE WORLD. BY 1983 MORE THAN 70 PERCENT OF THE 18,600 MEMBERS OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS IN 112 COUNTRIES WERE INVOLVED IN REFLECTION SEISMOGRAPHY.

OKLAHOMA HISTORICAL SOCIETY WITH
OKLAHOMA-KANSAS OIL & GAS ASSOCIATION
[illegible]

Figure 2 The memory for the first pilot testing of the reflection seismic technique, as well as the scheme of the reflection seismic principle located close to Oklahoma City (photo P. Blaha).

Since 1921, the reflection seismic developed immensely. Explosives are no longer the only choice for energy sources. Vircators are most often used on land and air guns for marine surveys. Detectors (geophones on land and hydrophones for marine) have become smaller and more powerful. The recording progressed from analog recording on photographic paper to digital recording on magnetic tape. Processing has evolved from a few manual operations to sophisticated software applications on computers (e.g. Gadallah and Fisher, 2005). However, the largest changes occurred in 80ties and 90ties of the 20th century when 3D (and later 4D) seismic technique has been gradually applied for industrial hydrocarbon exploration. The change brought not only new technologies for gathering the raw seismic data but also new sophisticated software and LogRhythm for seismic processing and following interpretation. The appearance of 3D seismic brought a new wave of interest in studying recent processes and forms as analogs for ancient sediments and their forms mapped by seismic. 3D reflection seismic data provide interpreters with the ability to map structures and stratigraphic features in 3D detail to a resolution of a few tens of meters over thousands of square kilometers (Fig. 3). It is often compared to geological "Hubble", whose resolving power has already yielded some fascinating (and surprising) insights and will continue to provide a major stimulus for geological processes research (Cartwright and Huuse, 2005). The 3D seismic provided enoran moues volume of geological information, which has recently been a challenge for new artificial intelligence (mainly machine learning, neuron networks) to a rectangle.

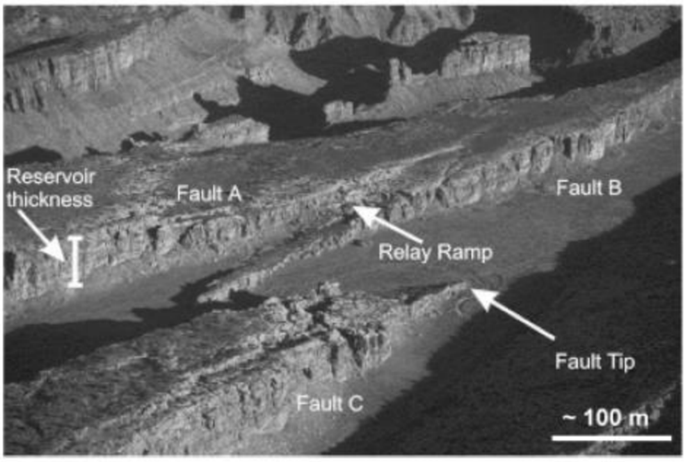


Figure 3: Fault intersections and relay structures interpreted from 3D seismic data (from Cartwright and Huuse, 2005).

Even that from the viewpoint of industrial use (and related business) is the oil industry main user of profits coming from seismic, it is necessary to mention that seismic technique has also a significant application in other fields of industry – mainly in engineering geology, hydrogeology and exploration of geothermal sources. However, in these fields, the application of refraction seismic and refraction seismic tomography predominates and reflection seismic is applied only occasionally.

Seismic survey for engineering geology is usually performed in relatively shallow depths (ca. up to 100 m). For that reason, the seismic used for this purpose is often called "shallow seismic". The hardware, logistical, time, and financial requirements for shallow seismic are much smaller than for the "conventional" industrial, deep seismic. The shallow seismic requires a relatively weak source – it can be a hammer, mechanical hammer, or explosives, relatively small channel number (usually used 24 or 48 channels). It also is not that demanding on geophones – we usually use single geophone at a certain distance and "nests" of geophones are not common compared to industrial seismic (Fig. 4).

Figure 4 Array of geophones connected by a cable during a shallow seismic data gathering (volcano n.d.).

1.2 Principle of Shallow seismic exploration

Shallow seismic exploration is a geological and geophysical engineering exploration that detects shallow geological structures (usually tens to hundreds of meters) and determines the physical and mechanical parameters of rock and soil by using seismic wave propagation characteristics in different rocks and soils. Different exploration methods can be utilized to achieve various aims, goals, and geological conditions. Based on seismic wave propagation modes, shallow seismic may be divided into three types: refraction wave technique, reflection wave method, and retraction wave method. Based on the modes of excitation and reception employed, as well as the position of the lateral line, shallow seismic research can be classed as S-wave exploration or P-wave exploration., based on the manner of excitation and reception, and it can also be characterized as water surface exploration, underworking exploration, PS logging, and VSP seismic profile exploration, among other things (Anon, n.d.A).

Shallow seismic measurement, particularly seismic refraction tomography, is a versatile geophysical method with several applications. It enables the search and identification of interface paths, which assists in the resolution of geological, environmental, hydrogeological, engineering, geotechnical, and other problems.

1.3Principle of Deep seismic exploration

Deep seismic surveys are a form of geophysical survey that investigates subterranean geology and structures using seismic waves. Seismic waves are energy waves that pass through the earth's crust and are reflected or refracted by various layers of rock or other subsurface components. Energy sources (such as dynamite or a specialized air pistol) are employed in a deep seismic survey to create seismic waves that are transmitted into the earth. Geophones are sensors placed on the earth's surface to detect seismic waves traveling through the subsurface. Geophone data is utilized to provide a detailed depiction of the underlying layers and structures. Deep seismic surveys are often employed in the oil and gas industry. It is commonly used in the oil and gas industry to identify potential hydrocarbon reservoirs, but it can also be used for a variety of other purposes such as determining the location of mineral deposits, studying the structure of the Earth's crust, and identifying potential geothermal energy production sites. Seismic waves are frequently caused by a tiny explosion or a large weight striking the earth. These waves travel into the Earth's crust, where they are reflected back to the surface by different layers of rock and other subsurface materials. Surface sensors detect the reflected waves and record the information. Based on physical properties such as density and flexibility, seismic waves are reflected by diverse subsurface materials. In hydrocarbon exploration, seismic reflection surveys are conducted to find rock formations that may contain oil or natural gas. These hydrocarbons are commonly found in porous and permeable fluid-saturated rock formations such as sandstones or limestones. When seismic waves contact a layer of rock that is physically different from the layers above and below it, some of the wave's energy is reflected back to the surface. Geologists may create an accurate map of the subsurface and identify potential hydrocarbon sources by analyzing data from reflected waves. Seismic reflection surveys are just one type of technique that may be used.

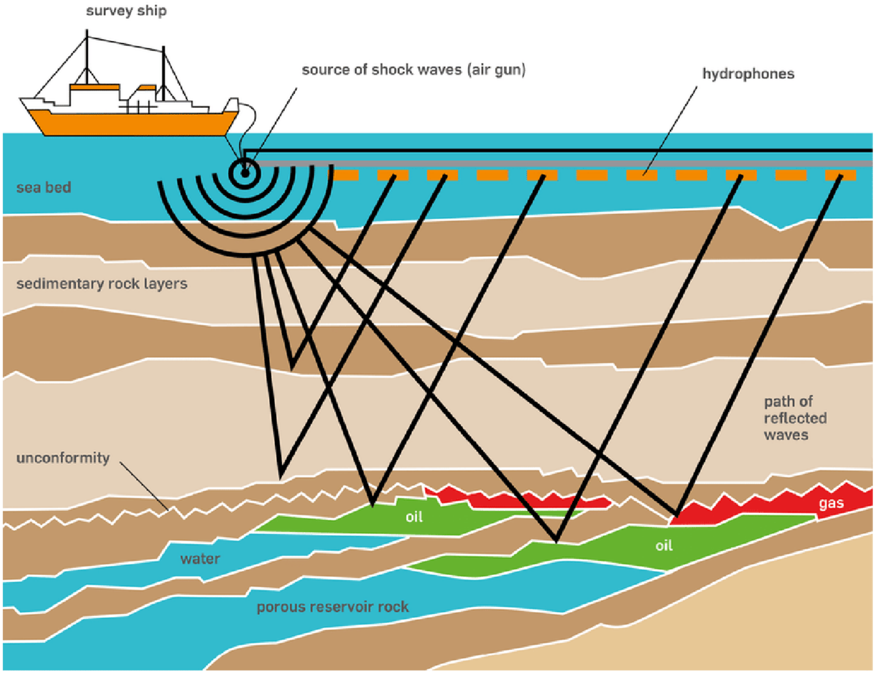


Figure 5   Offshore seismic survey, a example of Deep seismic survey for more than hundred meters below the sea level.

1.4 Principle of reflection seismic technique

The basic principle of the seismic comes from the fact that the spreading seismic wave reflects and refracts on the surfaces representing boundaries between rocks with different densities (Fig. 5). The seismic waves are generated by seismic sources and recorded by recording devices called geophones when on land or hydrophones when offshore.

2. Type of waves

The seismic waves have different behavior and properties. According to this, we can recognize **surface waves and body waves** (Fig. 4). Surface waves move slowly into the Earth's boundaries and have a lower frequency than body waves. They are easily distinguished on a seismogram. Surface waves generated by shallow earthquakes are stronger than surface waves generated by deeper earthquakes. We distinguish two types of surface waves: Rayleigh and L(love) waves.

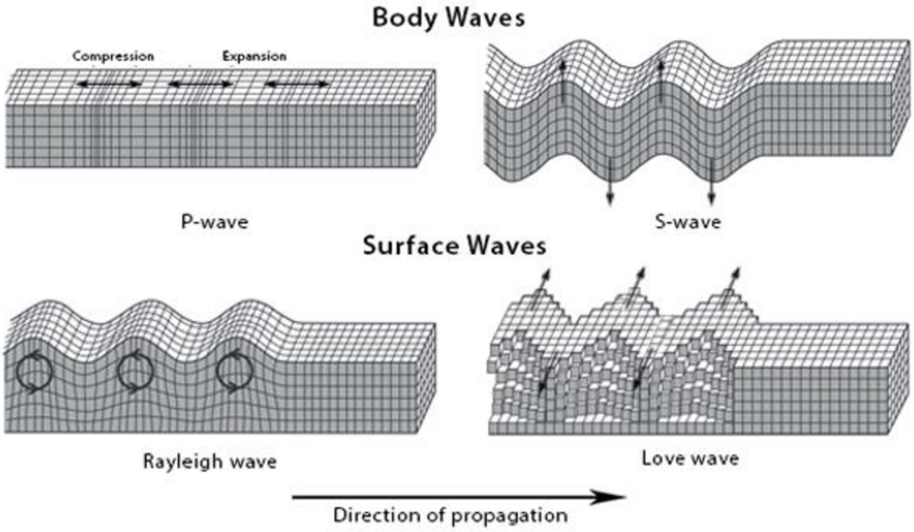


Figure 6 Main two types of waves when they travel underground (gktoday.in, n.d.).

2.1 Surface waves

Rayleigh Waves

Rayleigh waves have a more complex motion than Love waves when they roll down the ground. Rayleigh waves tend to roll like ocean waves, particle motion is the inverse of ocean waves. Because the earth rolls, it travels up and down, forward and backward in the direction of the wave. The Rayleigh wave, which can be significantly larger than the other waves, is responsible for the majority of the shaking experienced during an earthquake. The wave's amplitude, like that of Love waves, decreases significantly with depth. the motion of Rayleigh waves is a combination of longitudinal, and compressional (Michigan Technological University, n.d.).

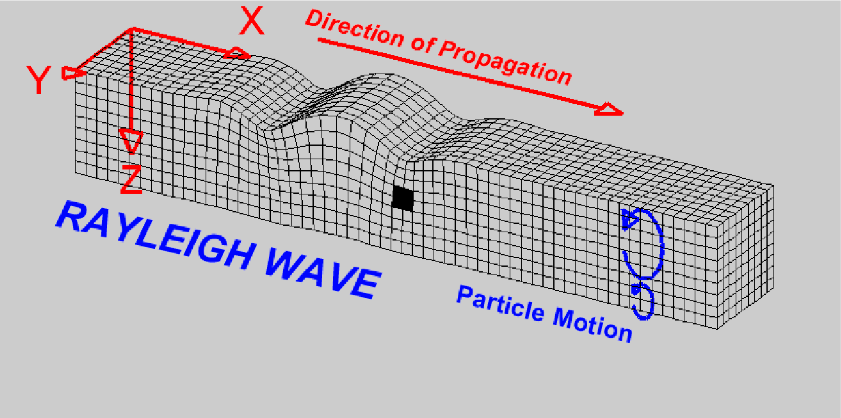


Figure 7 A Rayleigh wave travels through a medium. Particles are represented by cubes in this model image (Michigan Technological University, n.d.).

Love Waves

A love wave is a type of surface wave that moves totally horizontally. The amplitude increases with depth and diminishes towards the surface. The motion of particles of the Love wave makes a horizontal line perpendicular to the direction of propagation. Love wave particles, like S-wave particles, bounce back and forth perpendicular to the direction of wave transmission. The movement of Love wave particles results in the formation of a horizontal line perpendicular to the propagation direction. Love wave energy spreads out in two directions rather than three. With depth, the amplitude frequently falls fast. Rayleigh waves move more slowly than love waves (Michigan Technological University, n.d.).

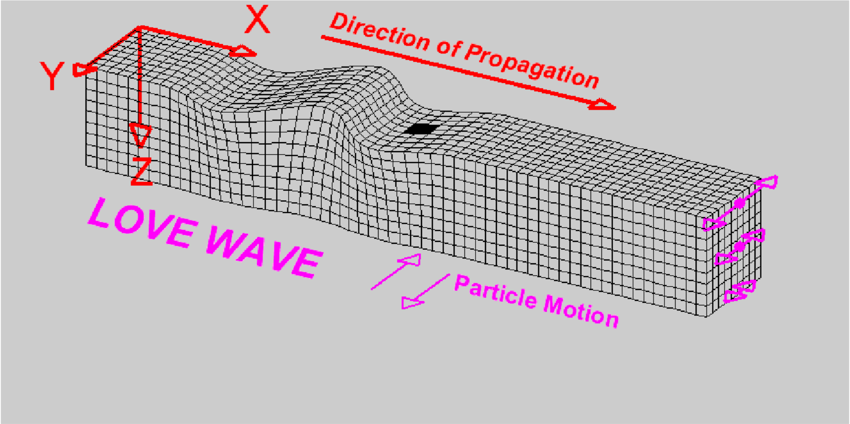


Figure 8 A Love wave travels through a medium. Particles are represented by cubes in this model image (Michigan Technological University, n.d.).

2.2 Body waves

P Waves

is one of body wave, is known as the primary wave, it is the strongest form of seismic wave and the first to reach a seismic station. They have the shortest wavelength and the fastest speed (5-7 km/s), and they are capable of moving through solids, liquids, and gases. In denser, solid materials, they travel fast (gktoday.in, n.d.). P waves may pass through solid rock as well as fluids such as water or the liquid layers of the Earth. It squishes and stretches the rock it passes through similarly to how sound waves compress and expand the air they pass through waves are characterized as compressional waves because they compress and pull. In the figure we it shows the shows the p wave effect on the rock particles by two main things which is compression and expanding the rock particle (Michigan Technological University, n.d.). Particles of the P wave move in the direction of the wave; it is the orientation of energy that goes, known as the "direction of wave propagation.

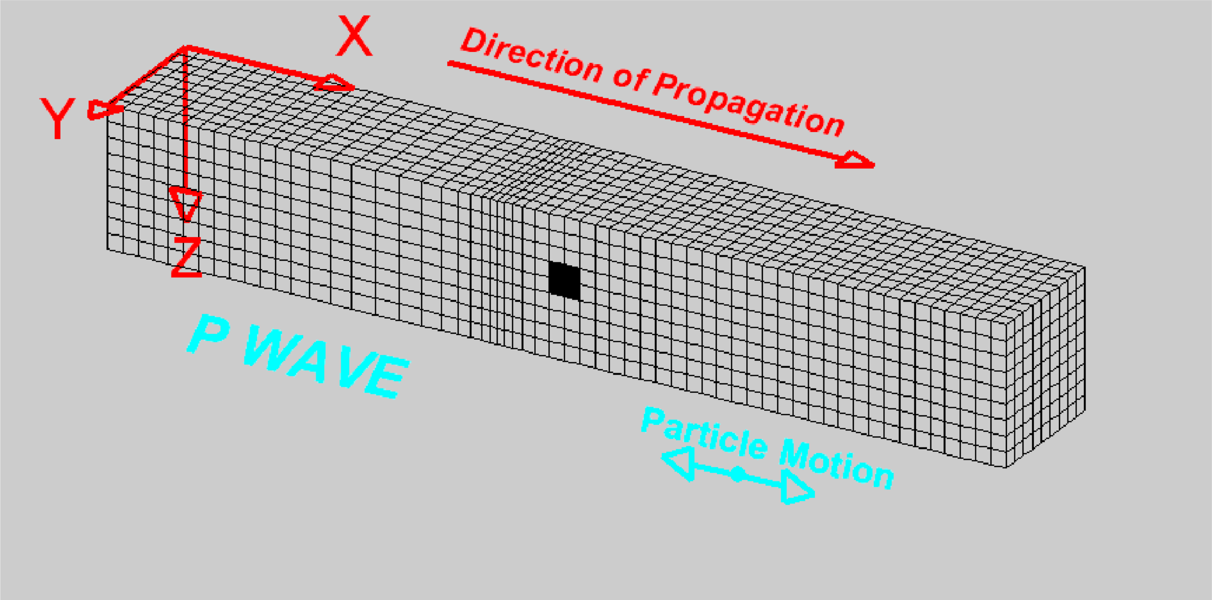


Figure 9 P-wave travels through a medium by means of compression and dilatation (Michigan Technological University, n.d.)

S Waves

The other type of seismic body wave is the S wave. P wave is about 1.7 times faster than S wave a. The main difference is that liquids can’t be detected if we use s waves because the S waves can’t move through it. S waves only move through solids. S waves move rock particles upward and downward, or from one side-to-other side. Secondary waves are transverse waves that produce vibrations perpendicular to the wave's travel direction. They are also known as Sheer waves or shock waves (Michigan Technological University, n.d.). S waves can only move through solids because liquids and gases lack sheer strength. They have a medium wavelength and produce vibrations that are perpendicular to the wave's propagation direction. Their top speed is between 3 and 4 kilometers per second. (gktoday.in, n.d.).

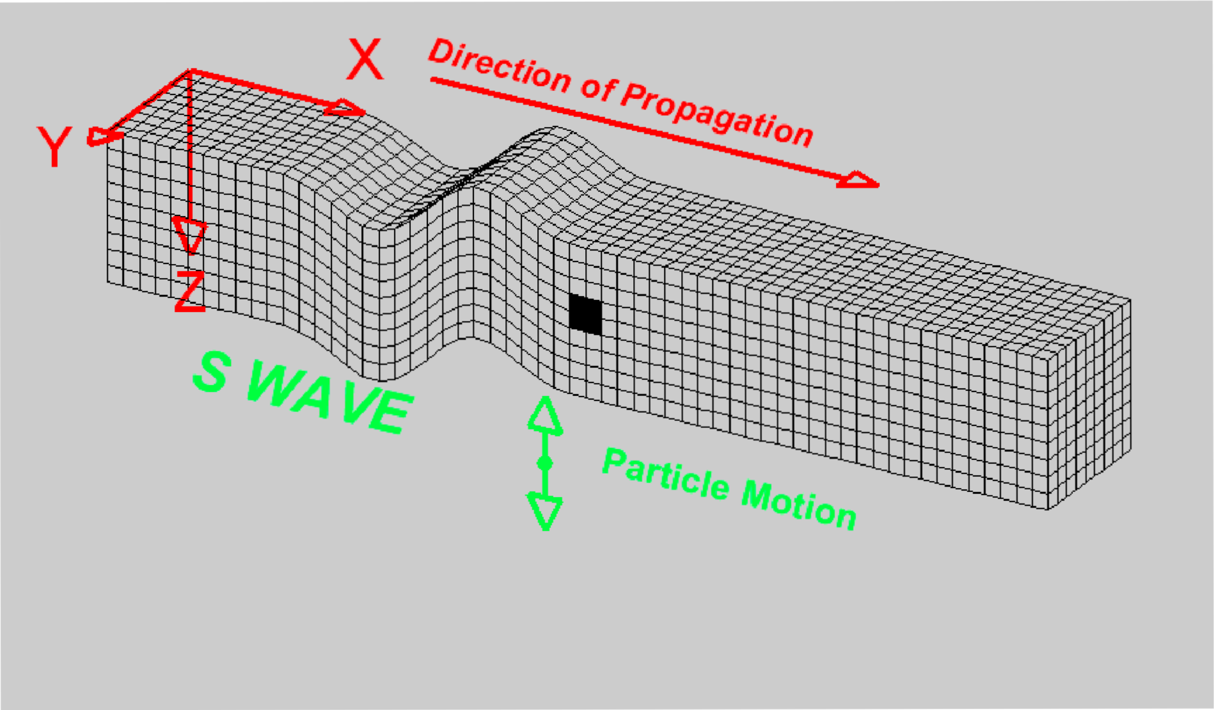


Figure 10 S wave travels through a medium by shear motion. Particles are represented by cubes in this model Particle motion shown here is vertical but can be in any direction perpendicular to the direction of the propagation image (Michigan Technological University, n.d.).

2.3 Seismic wave characteristics:

There are several characteristics of seismic waves that play an important role in the interpretation of seismic sections. The main characteristics are as follows (see also Fig. 9):

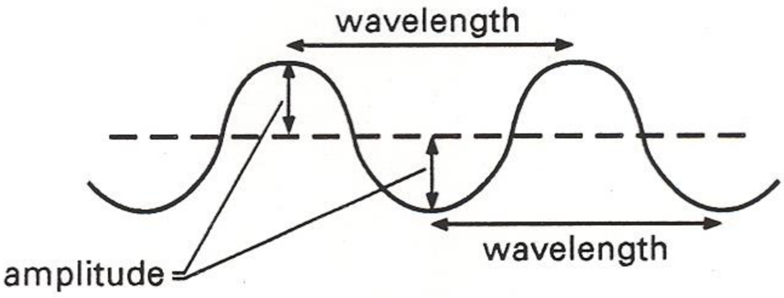


Figure 11 Amplitude and wavelength belong to seismic wave characteristics (sites, n.d.).

- amplitude
- wavelength
- frequency
- seismic velocity

Amplitude is height of the wave peak above the medial line of the wave (see Fig. 9).

Wavelength is a length between two wave peaks (see Fig. 9).

Frequency is the number of peaks passing one point in a second (Hz).

seismic velocity – the speed at which the waves move; depends on lithology.

Velocity = wavelength * frequency

The velocities and wavelengths of seismic waves increase with depth in the ground, while the frequencies decrease.

If the velocity of the seismic wave through the rocks is known or predictable, the two-way time may be converted to depth using the formula depth = two-way time x velocity / 2

The seismic velocity is one of the main issues during seismic shooting. The velocity is influenced by mineral composition, lithology, porosity, and pore fluidity, as well as the medium's elastic properties and bulk densities. degree of saturation and compaction or rocks (Tab. 1). The velocity analysis is one of the most important items during seismic processing.

Table 1 Examples of seismic velocities in different sediments and rocks (Pavlovi, 2001).

Type of formation	P waves velocity (m/s)	S waves velocity (m/s)	Density (g/cm^3)
Dry sand	400-1200	100-500	1.5-1.7
Wet sand	1500-2000	400-600	1.9-2.1
Limestone	3500-6000	2000-3300	1.4-2.7
Chalk	2300-2600	1100-1300	1.8-3.1
Salt	4500-5500	2500-3100	2.1-2.3
Anhydride	4000-5500	2200-3100	2.9-3.0
Dolomite	3500-6500	1900-3600	2.5-2.9
Granite	4500-6000	2500-3300	2.5-2.7
Basalt	5000-6000	2800-3400	2.7-3.1
Coal	2200-2700	1000-1400	1.3-1.8
Water	1450-1500	-	1.0
Oil	1200-1250	-	0.6-0.9

3. Seismic sources

A seismic source is any apparatus that discharges energy into the earth in the form of seismic waves and is referred to as a seismic source (Sheriff, 1991). There are two types of seismic sources: terrestrial seismic sources and marine seismic sources. The parameters of seismic waves generated by land seismic sources best fulfill the requirements for terrestrial seismic exploration. Similarly, marine seismic sources are used in water since they are best suited for marine exploration (Lsu.edu, 2022).

Acquisition, processing, and interpretation of seismic signals in exploration

Three fundamental steps of seismic exploration are data collection (acquisition), processing, and interpretation. All of them determine the resolution of the seismic method

3.1Data acquisition

The fundamental purpose of seismic surveys is accurately to record the ground motion caused by a known source in a known location. The record of ground motion with time constitutes a seismogram and is the basic information used for interpretation through either modeling or imaging. The essential instrumental requirements are to:

- Generate a seismic pulse with a suitable source
- Detect the seismic waves in the ground with a suitable transducer
- Record and display the seismic waveforms on a suitable seismogram.

3.2Land seismic sources

It is desirable to generate a highly energetic wave of a short duration that is repeatable and does not generate noise that interferes with detection. Impulsive sources are the most commonly used sources. The most common type of seismic survey source is the dynamite or Vibriosis, hummer. Typically, an explosive source is used by shallow drilling at the desired location; the charge is placed in the hole with a loading pole (to insure it achieves the proper position), and the charge is detonated with an electrically ignited blasting cap (Lsu.edu, 2022).

Today, the most commonly used seismic source for industrial seismic on land is vibriosis. It is the most common non-explosive source used for reflection surveying. It uses truck-mounted vibratos to pass into the ground and extended vibration of low amplitude and continuously varying frequency, known as a sweep signal. A typical sweep signal lasts from several seconds up to a few tens of seconds and varies progressively in frequency between limits of about 10 and 80 Hz. The field recordings consist of an interfering reflected wave of very low amplitude that is hidden in the ambient seismic noise.

Figure 12 Vibriosis and metal plate mounted on the track. Photo J. Janocko.

The explosives are commonly only used in hardly accessible terrains. Explosives are inserted in shallow (5 – 10 m deep) boreholes and then blast (Fig. 11).

Figure 13 Explosives for blasting in shallow boreholes (piratemonkeyMore, n.d.).

The sources of seismic waves for shallow seismic usually serve mechanical hammers and hammers (Fig. 12).

Figure 14 Mechanical hummer that generate vibration in seismic survey (Geodevice, n.d.).

3.3Marine seismic sources

Several types of marine sources have been developed to lessen the bubble effect. These sources are (Keary et al., 2002):

- Water gun (20-1500 Hz)
- Air Gun (100-1500 Hz)
- Sparker (50 4000 Hz)

Water gun is an adaptation of air gun to avoid the bubble pulse problem. Rather of being released into the water layer, the compressed air powers a piston, which ejects a water jet into the surrounding seawater. When the piston stops, a vacuum cavity created behind the advancing water jet and this implodes under the influence of the ambient hydrostatic pressure, generating a strong acoustic pulse free of bubble oscillations. no gas material is compressed and "bounces back" as bubbles pulse that's due to the vacuumed collapse that causes the implosion, the resulting short pulse length offers a potentially higher resolution than is achieved with air guns but at the expense of a more complex initial source pulse due to the piston motion.

Air Gun is most commonly used source of seismic wave offshore. The principle of the air gun is shown on Fig. 15:

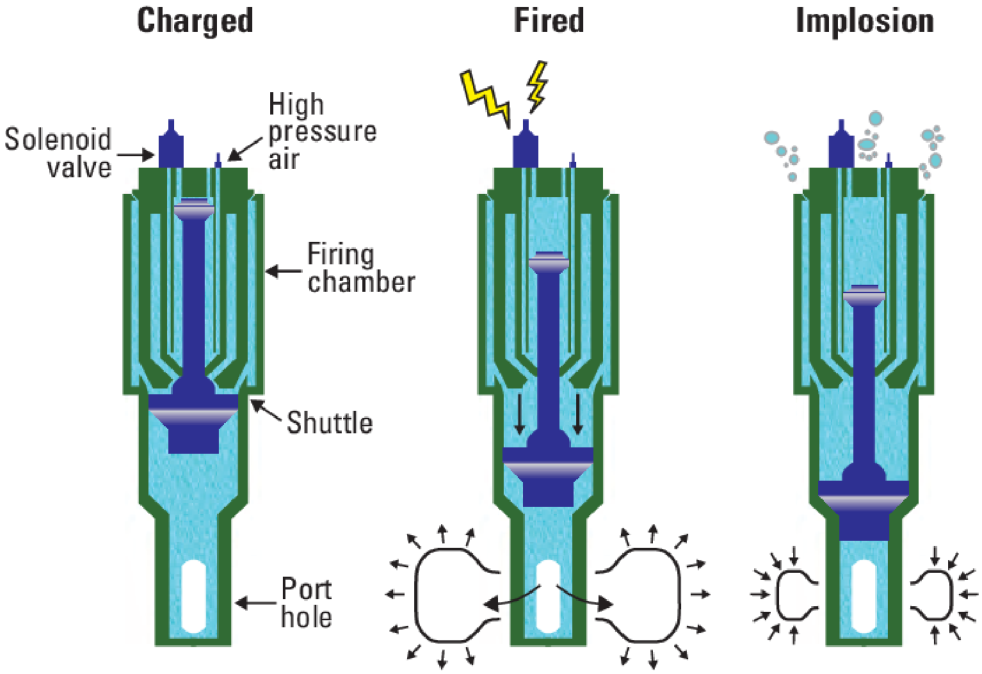


Figure 15 Design of Air gun in the charged case and in the implosion case (GEO ExPro, 2010).

The air gun is pneumatic source in which a chamber is charged with very high-pressure (typically 10 – 15 MPa) compressed air fed through a hose from a shipboard compressor. Air is expelled into the ocean in the shape of a high-pressure bubble by electrically activating the vents.

Sparker is device for converting electrical energy into acoustic energy. Created electrical spark vaporizes the sea water near the tip of the sparker array. This vaporized water rapidly expands, resulting in the formation of a pressure wave. Large, 12,000kJ sparkers can create lower frequencies (down to 50Hz) and penetrate to depths of 1000m.

Boomer — A low-frequency gadget capable of penetrating far deeper below the seafloor (dominant frequencies between 500 Hz and 5 kHz) (up to 100m). An induction coil and a metal plate are used to produce an audible pulse. It is possible to employ a single plate or a triple plate layout.

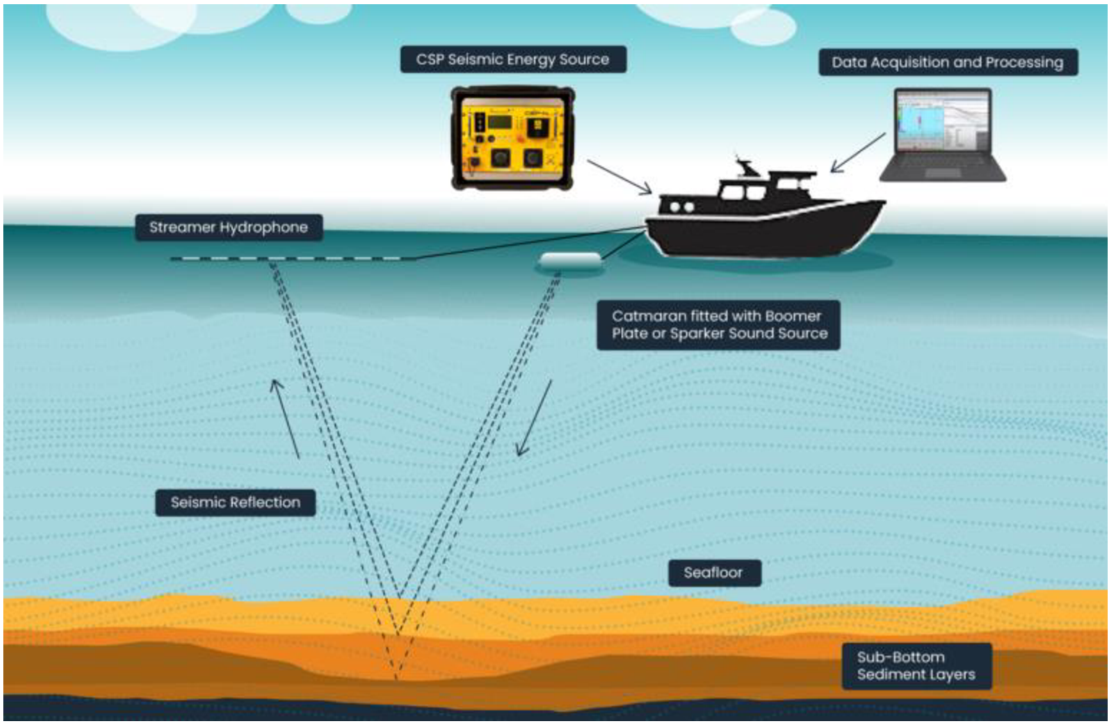


Figure 16 Scheme of setup for seismic data gathering offshore (Calvert, 2022).

4. Receivers – geophones and hydrophones

A reflected seismic wave is received by devices called geophones if on land or hydrophones if offshore.

4.1 Geophones

Seismic geophones are sensors that convert ground movement or vibration into a voltage that the acquisition system can detect. The geophone response is the divergence of this recorded voltage from the baseline, and it is used to analyze the earth's structure, reflect the inner structure of the earth's crust, or monitor vibration caused by nature, people, or industrial engineering. Geophones typically use a spring-mounted wire coil moving inside the field of a case-mounted permanent magnet to generate an electrical signal. The response of the geophone coil is linked to ground velocity. The frequency response of a geophone is a form of harmonic oscillator that is governed by the comer frequency (typically about 10 Hz) and dampening (Michigan Tech).

Figure 17 Land geophones that are utilized in theland seismic survey (geostuff.com, n.d.).

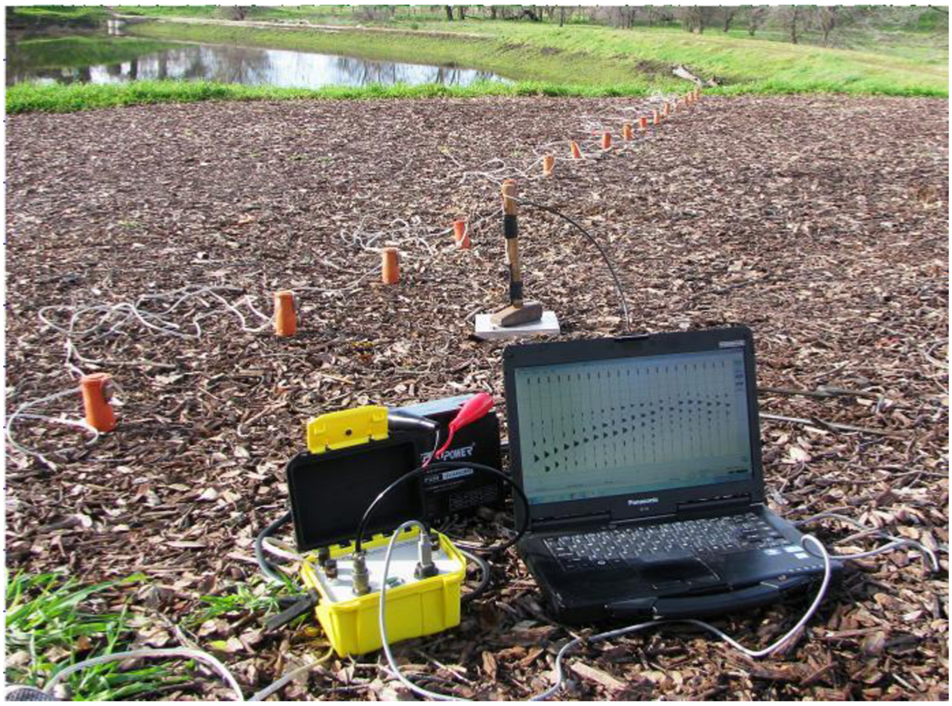


Figure 18 Set-up of geophones. Depicted is also a central unit (geostuff.com, n.d.).

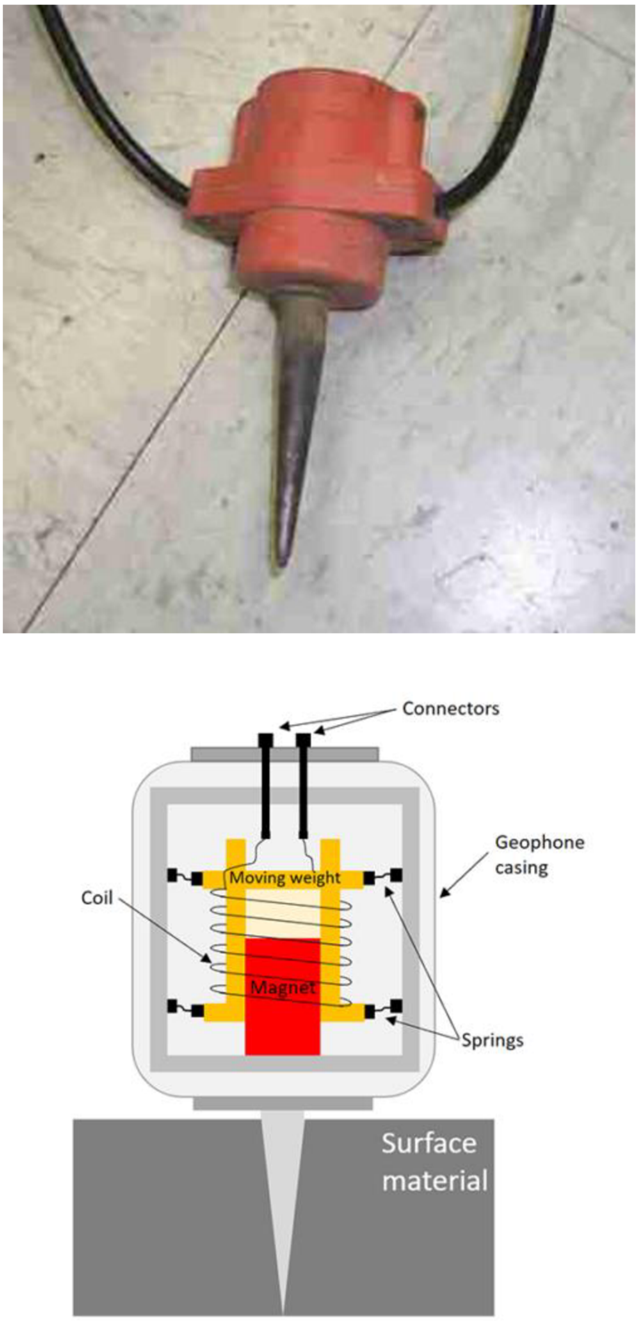


Figure 19 Scheme of geophone (generally 0.707).

The response of the geophone coil is proportional to ground velocity. The frequency response of a geophone is a form of harmonic oscillator that is determined by the comer frequency (often around 10 Hz) and damping (generally 0.707), however, it is possible to lower the comer frequency electronically at the penalty of increased noise and cost.

Although ground waves have three dimensions, geophones are frequently confined to reacting to a single dimension, usually the vertical. However, certain applications require the complete wave to be used, hence three-component or 3 - C geophones are used in analog seismic devices, with three moving geophone components stacked in an orthogonal structure within a 3C geophone container. The vast majority of geophones are utilized in reflection seismology. Certain applications, however, necessitate the utilization of the whole wave, hence three - components or 3 - C geophones are utilized in analog seismic devices, with three moving geophone components stacked in an orthogonal structure within a 3C geophone container. The vast majority of geophones are used in reflection seismology to record energy waves reflected by subsurface geology, however, geophones are increasingly being utilized in industrial vibration, safety monitoring, and internet of things engineering (Michigan Tech)

4.2 Hydrophones

Analogue of geophones on land are hydrophones used offshore. With hydrophone-carrying steamers suspended below the surface, massive seismic survey boats are used. Sound waves are projected from the ship by compressed air cannons, which penetrate the bottom and bounce back from the various rock layers. These reflected sound waves are detected by hydrophones placed along seismic streamers and processed to generate a three-dimensional picture of the substrate.

Seismic survey vessel usually tows several streamers behind them (from 1-12) and of varying lengths up to 5 000 m. They show shapes and lights for a vessel restricted in its ability to maneuver. The streamers (cables) are spread by diverters, similar to a type of mid-water trawled door and can extend to over 500 m in width. The end of each streamer is marked by tallboy carrying radar reflectors and flashing lights (US Department of Commerce, n.d.).

Seismic survey vessels tow at a speed of 4 5 knots and need to be on a straight line whilst surveying and are usually accompanied by a “Chase Boat” that will assist in notifying other vessels of the seismic operation. Survey areas vary greatly in size and may cover extensive areas of the sea surface (Fig. 20).

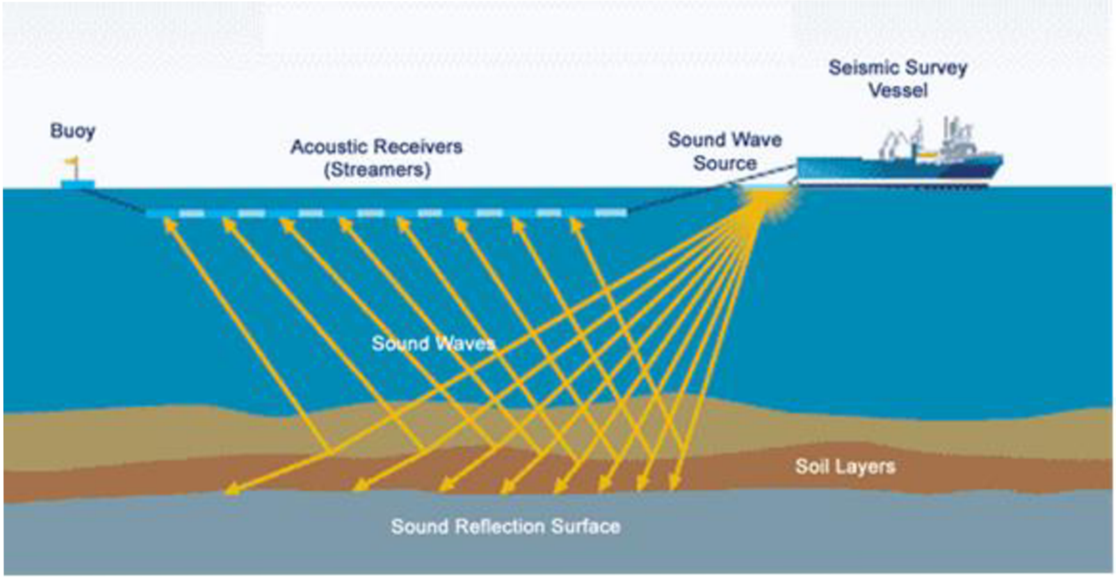


Figure 20 Set-up of the vessel, seismic source, and hydrophones (Anon, n.d.B).

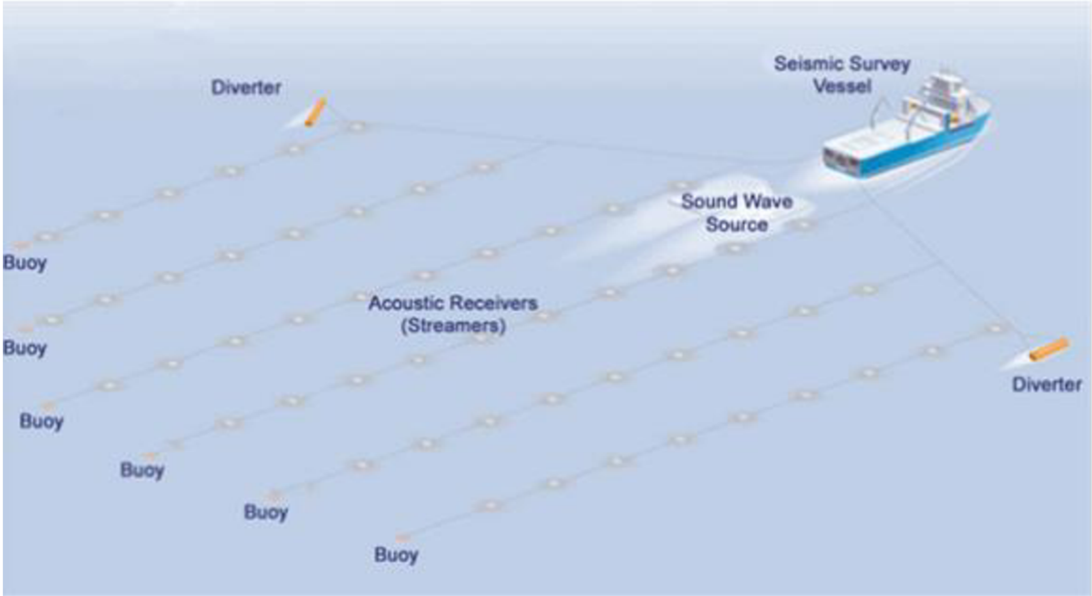


Figure 21 Seismic survey vessel and associated equipment (Surface Waves | UPSeis | Michigan Tech, no date)

Figure 22 All the small kinds of hydrophones (Surface Waves | UPSeis | Michigan Tech, no date)

4.3 Seismograph ABEM Terraloc

The ABEM Terraloc Pro is a stand-alone system that includes a computer, data storage, measurement channels, and a user interface. Measurements are carried out through the use of a graphical interface with a familiar look and feel. The system is enclosed in a robust and durable aluminum casing that fulfils IEC IP 66 specifications, allowing measurements to be conducted in a variety of conditions and locations. The ABEM Terraloc Pro may be configured using approximately 48 channels in a single device, allowing for many sensors and high data resolution. If more channels are necessary, several units can be coupled together. The cutting-edge technology employed in the measurement channels results in remarkable signal resolution in both terms of time and amplitude. As a result, data quality is unparalleled (GPR, n.d.).

Figure 23 Seismograph ABEM Terraloc (GPR, n.d.).

Methodology

Seismic methodology refers to the techniques and methods used to study earthquakes and the Earth's subsurface using seismic waves. Seismologists use seismic waves to create images of the subsurface, which can help them understand the structures and composition of the Earth's crust and mantle. This information is important for a variety of applications, including studying earthquakes and predicting their potential impact, exploring natural resources, and understanding the processes that shape the Earth's surface. The seismic methodology involves using a variety of techniques, including seismograph networks, computer modeling, and data analysis, to study seismic waves and interpret the information they contain. Seismic sources are used in a variety of applications, including the exploration of natural resources, such as oil and gas, and studying the Earth's subsurface for geological and geophysical purposes. There are several different types of seismic sources, including explosives, air guns, and vibrators, which generate different types of seismic waves. These waves are detected by seismometers or other instruments, which measure their movement and intensity, allowing seismologists to create images of the subsurface and study the structures and composition of the Earth's crust and mantle. My work is focused on showing the basic principles of reflection seismic, its application, and, an example of an analysis of seismic sections. Based on this, my main work method was research searching the literature describing the seismic methods and extraction of the most essential knowledge from reading articles and books. The important part of the methodology was to structure the knowledge gained from different literature sources in order for the reader of my thesis can orient easily in the given problematics.

- The methodology used during the analysis of seismic sections from the Kosice Depression consists of:
- Literature search for getting knowledge on the geological background
- location of seismic sections (base map)
- analysis of seism facies of the sections based on seismic properties (frequency, amplitude, lateral consistency)
- Description of seism facies

Seismic interpretation

The processed seismic sections are provided for seismic interpretation. Even if the interpretation is done by sophisticated software's today, knowledge on several geological disciplines like structural geology, sedimentology, sequence stratigraphy is necessary for successful analysis of seismic. This fact stresses important role of interpreter – even if the seismic sections is interpreted by mean of sophisticated software, subjective view of the interpreter is very important. At the first stages of interpretation, attention is given to descriptive characteristics of individual reflections. Individual reflections have several measurable and descriptive properties that can be related to geology. These properties are (Fig. 27):

- Reflection continuity: depends on the continuity of impedance contrasts along a strata surface
- Reflection amplitude: depends on reflection coefficient
- Reflection frequency: reflects bed spacing
- Reflection polarity: change of polarity indicates type of lithology

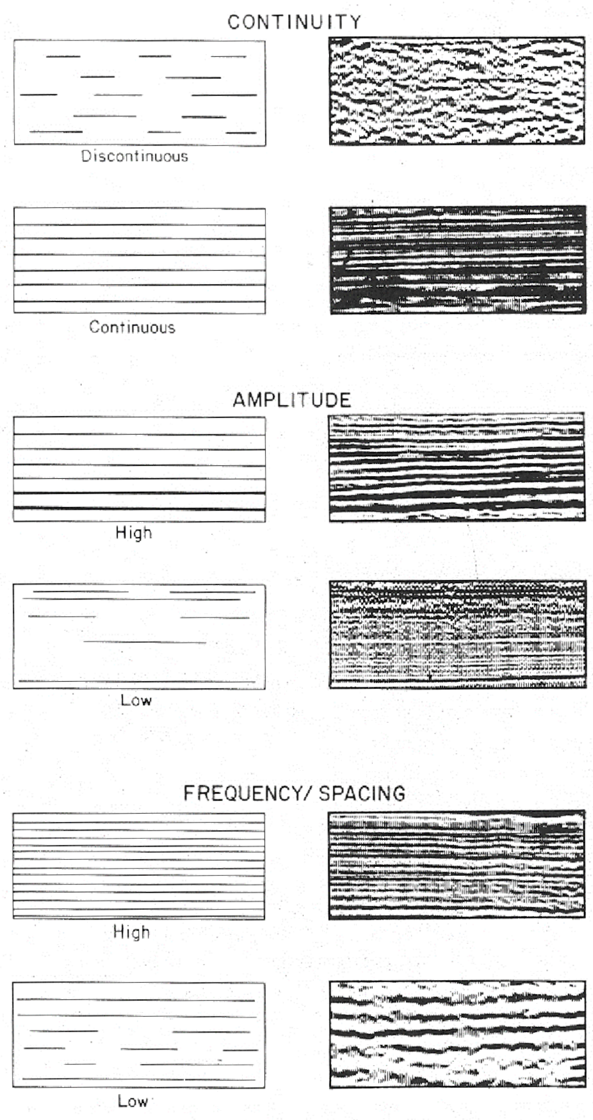


Figure 24 Reflection attributes: continuity, amplitude, frequency. From Baley, 1991.

In addition to this attribute we analyze the reflection geometry (Fig. 28). The geometry can directly suggest type of depositional environment.

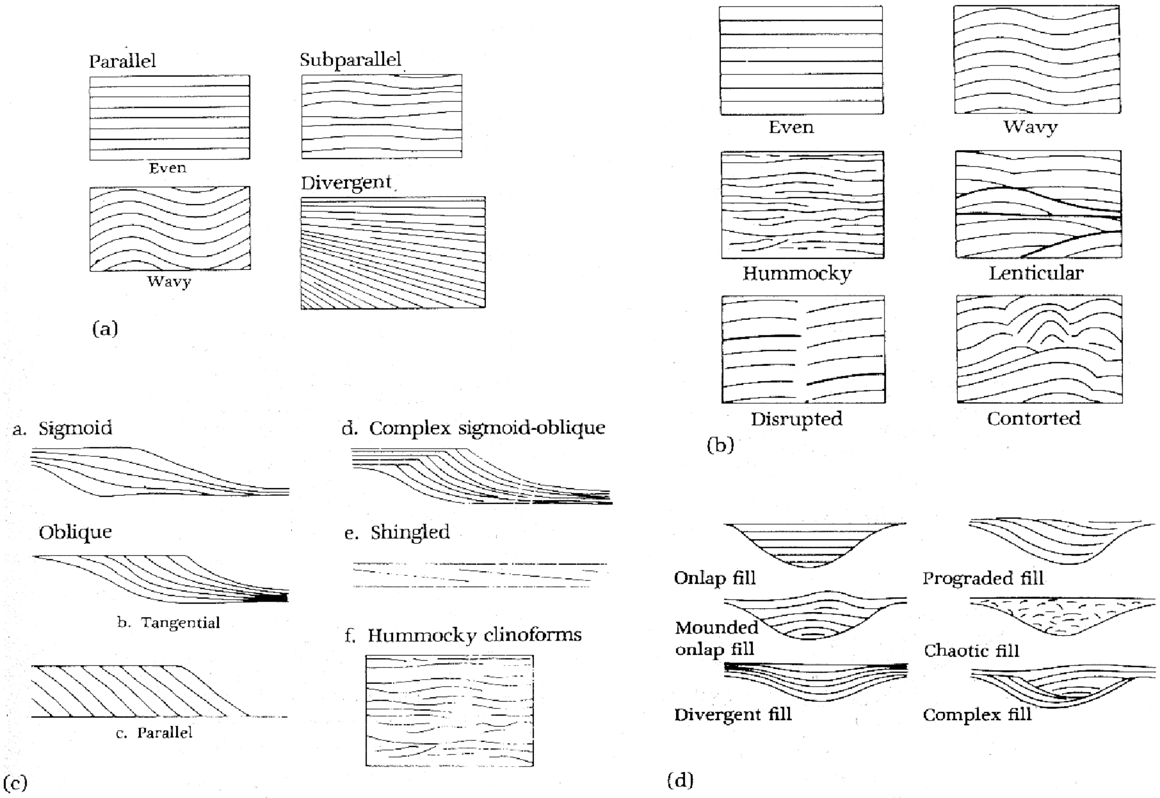


Figure 25 Examples of diagnostic reflection configurations. From Baley, 1991.

Based on above mentioned characteristics we can define seismic facies. Seismic facies units are 3D packages of stratigraphy and their external form providing additional information on depositional environments / processes.

Descriptive terms for external forms include: sheet, wedge, lens, mound, fan, lobe, channel, mass-transport deposits, drape (Fig. 29 and 30).

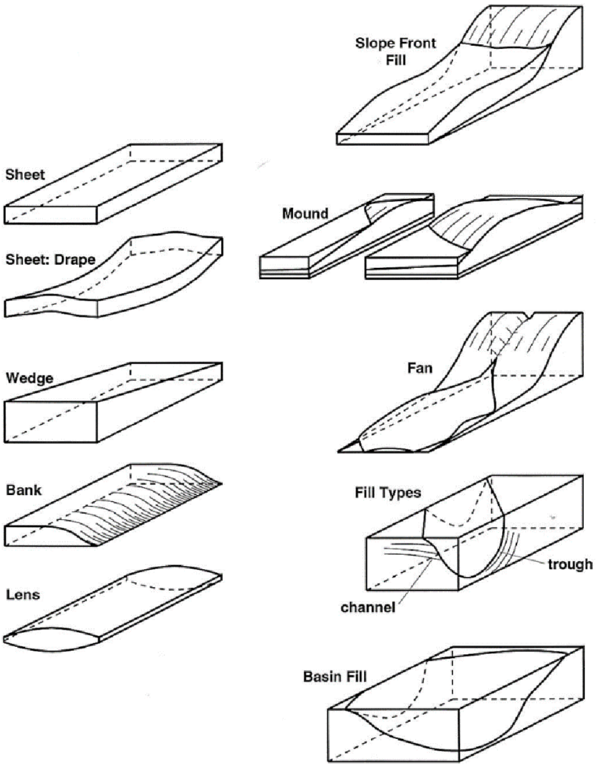


Figure 26 External forms of seismic facies. From Badley, 1991

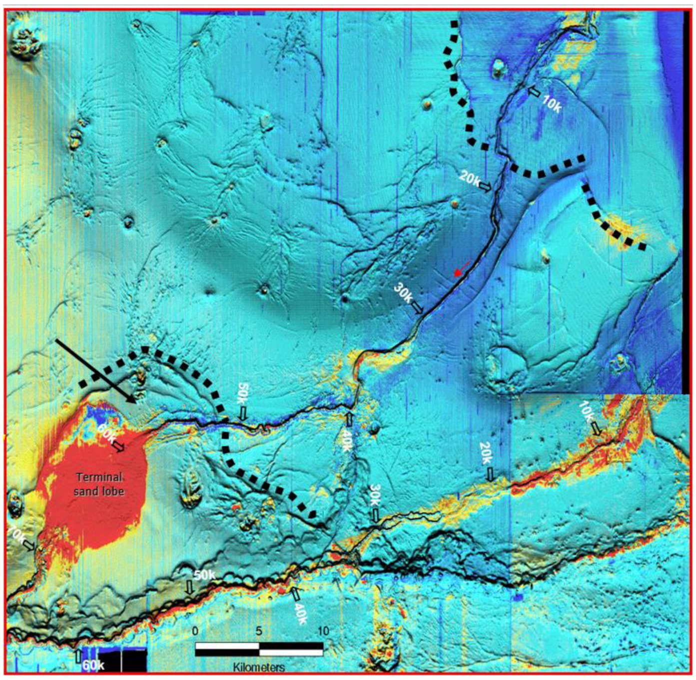


Figure 27 Distribution channel and fan of deep-water turbidite system. From Pirmez et al., 2000

Data processing

Geophysical data assess the relationship between a physical quantity and time or location. The seismic data basically show by mean of seismogram showing the variation of the measured quantity with respect to time. The seismogram shows complex waveform shapes, which will reflect physical variations in the underlying geology, superimposed on unwanted variations from non-geological features (such as the effect of electrical power cables, vibration from passing traffic, etc.), instrumental inaccuracy, and data collection errors. The detailed shape of the waveform may be uncertain due to the difficulty in interpolating the curve between widely spaced stations. The geophysicist's goal is to separate the "signal" from the "noise" and interpret the data in terms of ground structure. Noice is a term covering all phenomena unrelated to geology (to the primary reflections) that have to be recognized and disregarded in an interpretation. Common sources of noise are multiples, reverberations, diffractions, etc. The analysis of waveforms is done by application of physics and mathematics (Zhou, 2014).

Generally, we can recognize several steps of the processing:

1) demultiplexing - editing and reorganization of data; data belonging to single geophones are saved together.
2) static correction – compensation of differences between topographic elevation, velocity effects due to the surface weathered rock zone, depth of hydrophones (Fig. 22)

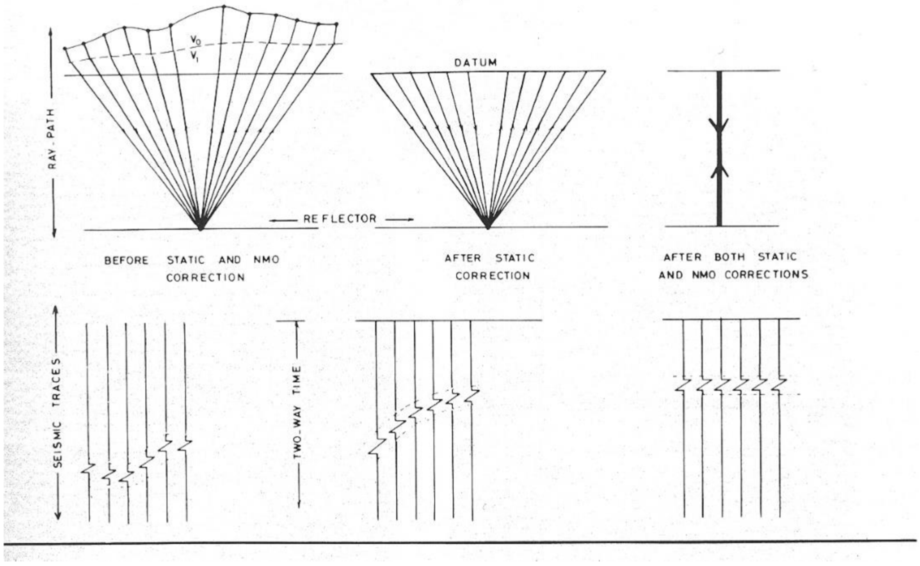


Figure 28 Static corrections – the ray path diagram (above) and seismic traces (below) show static and dynamic corrections to CMP gather. Baley, 1991).

deconvolution – a processing step in order to remove the tail of the signal and to make the signa short. The result of deconvolution is a sequence called wavelet (Fig. 23)

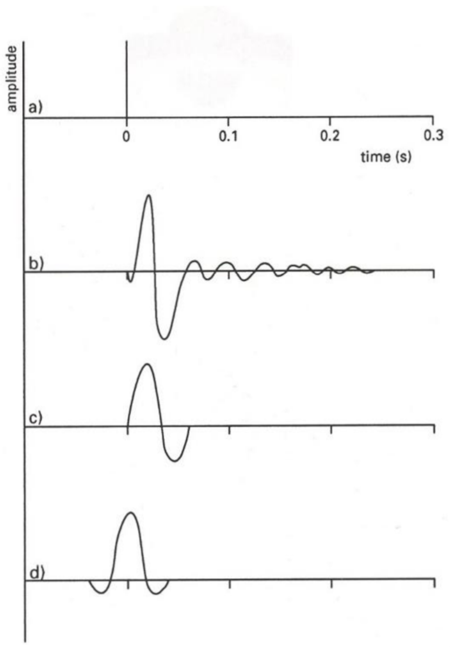


Figure 29 Deconvolution: the time scale starts at the instant the signal begins to meet a reflecting horizon. A) an instantaneous impulse, the ideal signal, and b) a typical real seismic signal. c) a minimum phase and d) zero phase wavelet, into which the real signal is converted during processsing.

3) making CDP gathers (traces are grouped into groups with common shot points) (Fig. 24)

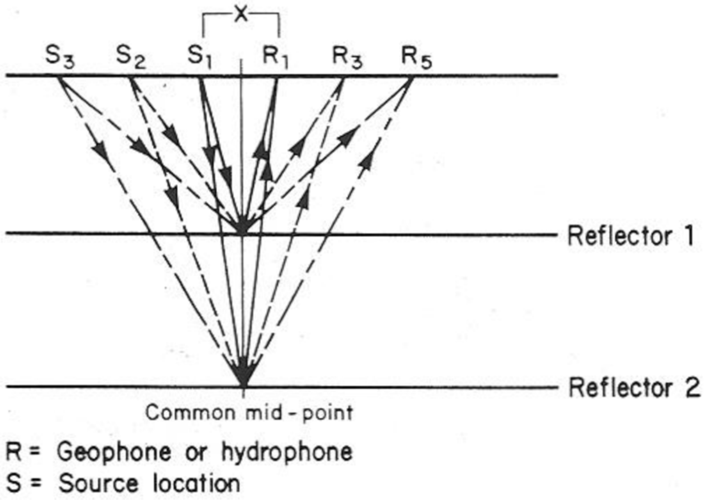


Figure 30 Geometry of the common-depth-point (CDP) gather for the subsurface location midway between the source and receiver. (archive.epa.gov, n.d.). velocity analysis – calculation of subsurface velocity.

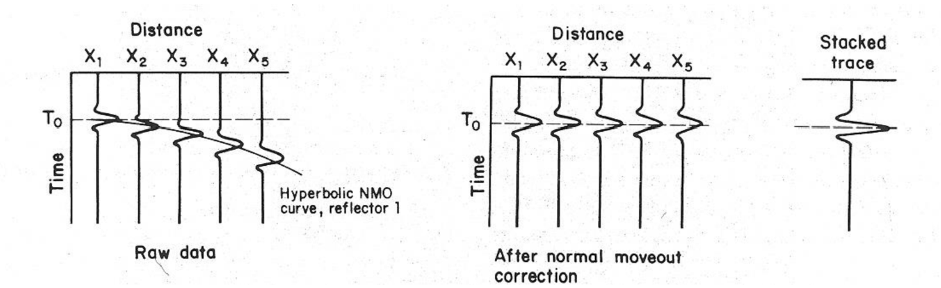


Figure 31 The normal move-out velocity can be calculated from the hyperbolic curve of reflection arrivals on a time versus offset (distance) plot. The normal move-out velocity brings a reflection to the same time for all offsets (middle picture). The addition of the correction of normal move-out velocity traces results in a stacked trace (right). (Developers, n.d.).

The normal move-out velocity can be calculated from the hyperbolic curve of reflection arrivals on a time versus offset (distance) plot. The normal move-out velocity brings a reflection to the same time for all offsets (middle picture). The addition of

Besides these steps, it is important to recognize another one phenomenon resulting from multiple bouncing of the seismic wave before arriving at the geophone called multiple. There are several types of multiples significantly influencing the resulting display of seismic lines (Fig. 26).

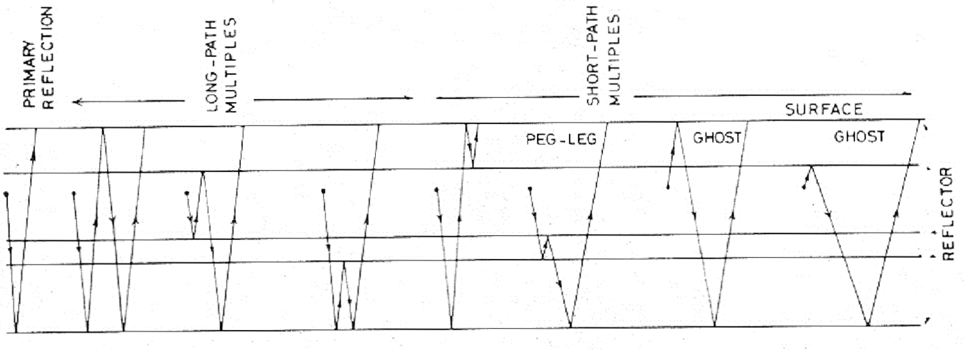


Figure 32 Common types of multiple reflections. After Baley, 1991.

Results

Geological setting

The East-Slovakian Basin is a basin with complex tectonic history determined by the oblique subduction of an oceanic slab occurring between the North-European Platform and the ALCAPA (Alpine-Carpathian-Pannonian) plate. The basin represents an autonomous part of the Transcarpathian Basin extending mostly on the Slovak territory.

The fill of the basin consists of sediments and volcanic stratigraphically ranging from the Greenbergian to the Pliocene. The maximum thickness of the fill is up to 8 - 9 km. The depocenters migrated in time from NW to SE. In the NW part of the basin the subsidence culminated in the Karpatian, in the central part of the basin it culminated during the Late Adenain, and finally, during the Early Sarmatian the highest amplitude of subsidence occurred in the SE part of the basin. Prevailing deposits are composed of siliciclastic, caustobioliths (coal and lignite), and minor evaporite deposits. An important portion of the basin fill is composed of volcanic rocks (mainly volcaniclastics and effusions). They are acid (absolutely)

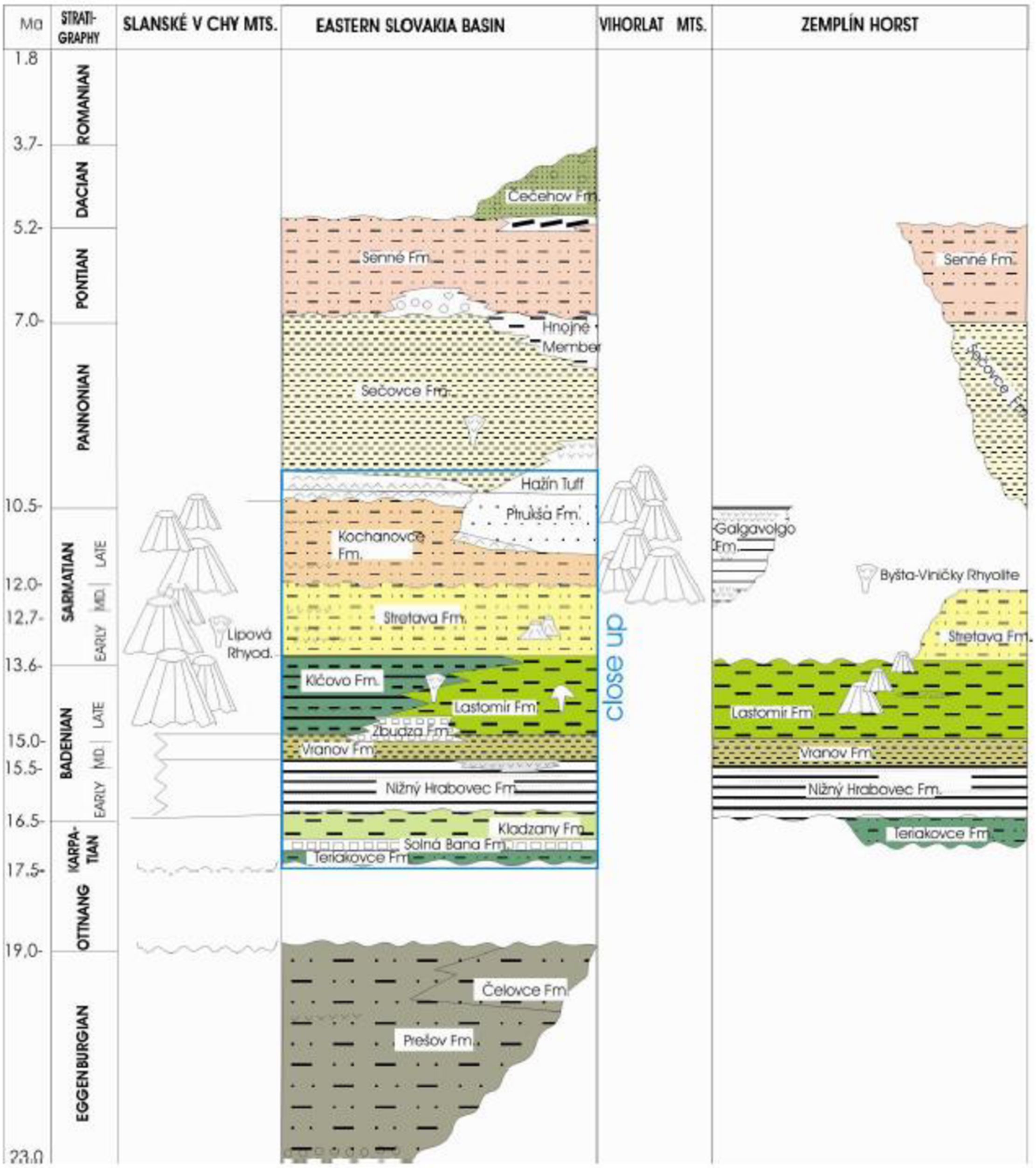


Figure 33Lithostratigraphic column of the East-Slovakian Neogene BasinVass et al., 2000.

.

The kinematic history of the basin is complex. The basin originated in a transgressional regime which later changed to compressional and trans tensional. The most important periods of basin development are connected with a pull-apart (Vass et al. 1988).

The basin fill is of horst-and-graben style which resulted from mainly nonrepetitional fault activity. The value of some fault system throws exceeds 1 000 m (Vass et al., 2000).

A striking morpho structure of volcanic rocks belonging to the Slanské vrchy Mts. divides the basin into two parts – the Prešov Depression in the west continuing into Moldava Depression in the south and the Trebišov Depression in the east with Roňava "Bay" in the southeast (Fig. 1). Both the Moldava Depression and Roňava "Bay" are formally assigned to the East-Slovakian Neogene Basin (Vass et al. 1988) although they are genetically part of the back-arc depression of the Carpathians.

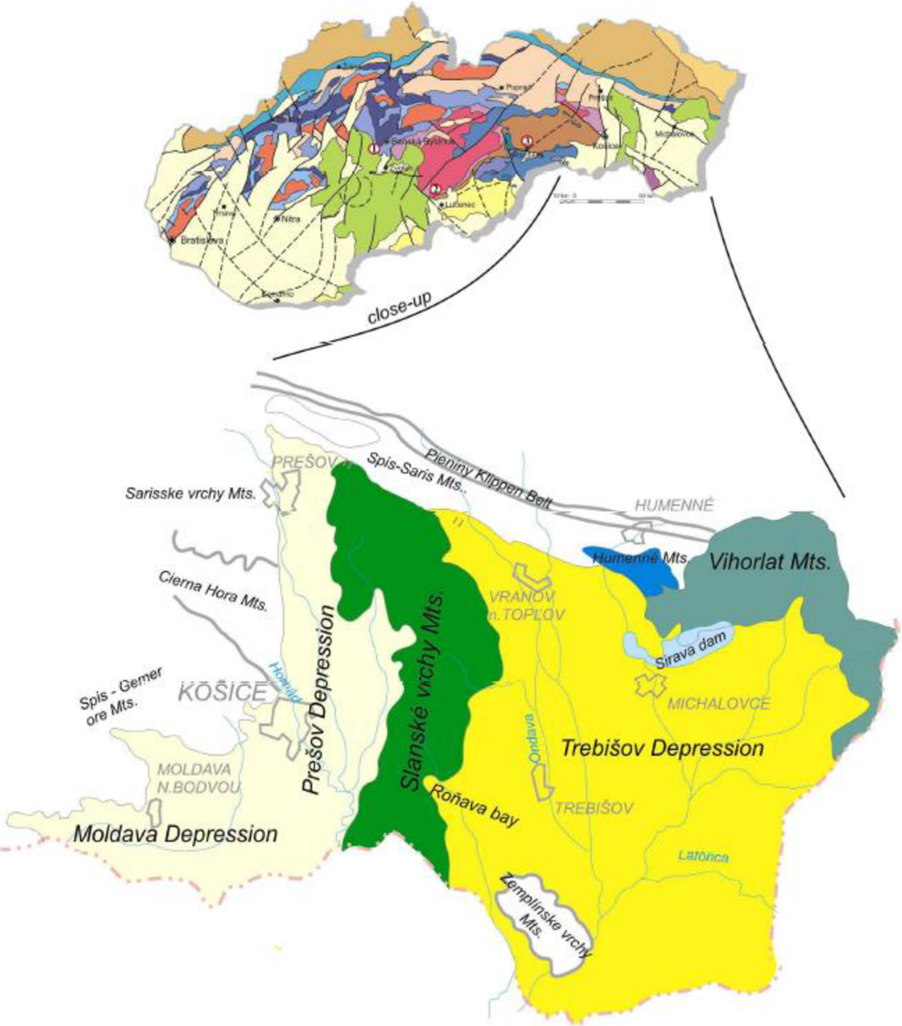


Figure 34 Division of the East-Slovakian Neogene Basin. (From Janocko.and Jacko, 2009).

Analysis of seismic sections

Six seismic sections were analyzed in order to find basic geologic and tectonic structure of the Kosice depression, which is a part of the East-Slovakian Neogene Basin. The location of the sections is depicted in Figs. 27, 28 and 29.

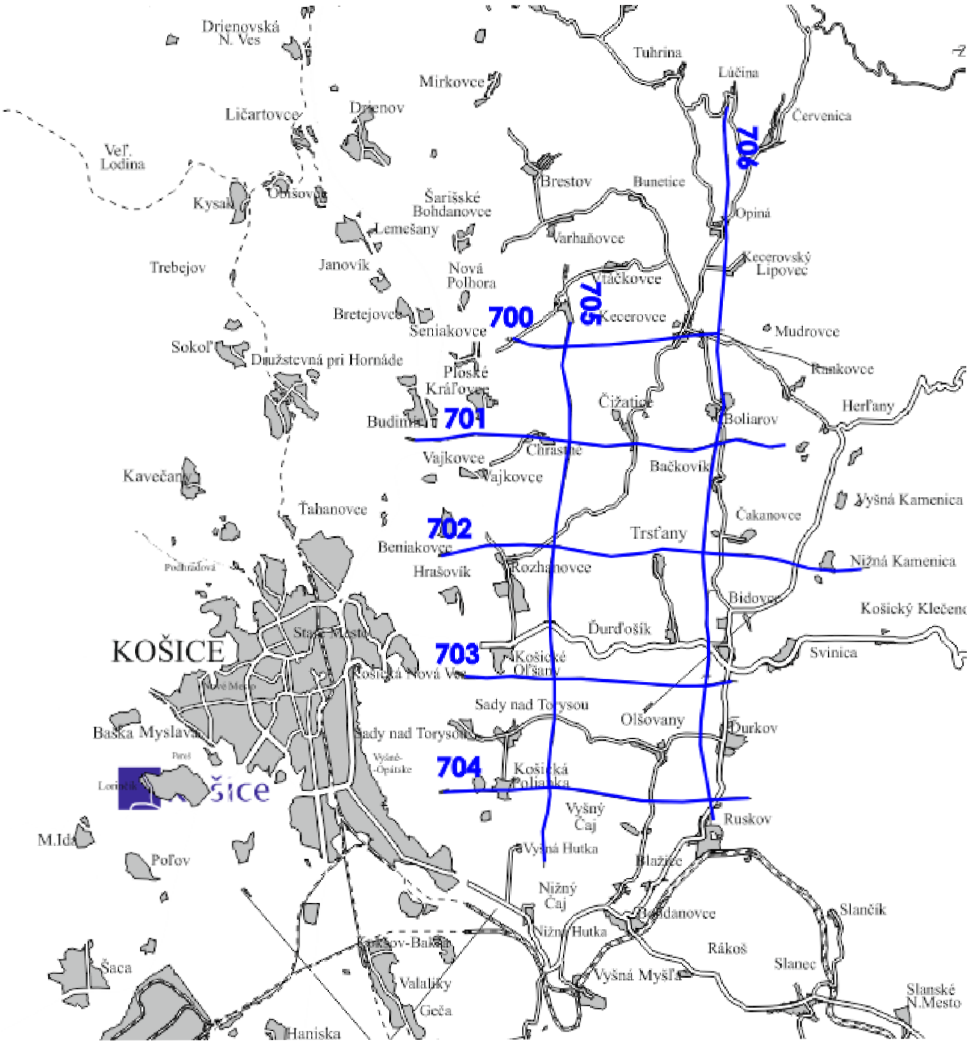


Figure 35 Location of studied seismic sections in the surroundings of Kosice.

The following image (Figs. 32and 33) shows seven seismic surveys combined together in order to make a 3D model to make it obvious from all directions and also to get the whole data from it. this step is for the geologist do it in order to compare the other images together and to know where the fault starts and where it gets to ends and which layer has the same form and properties

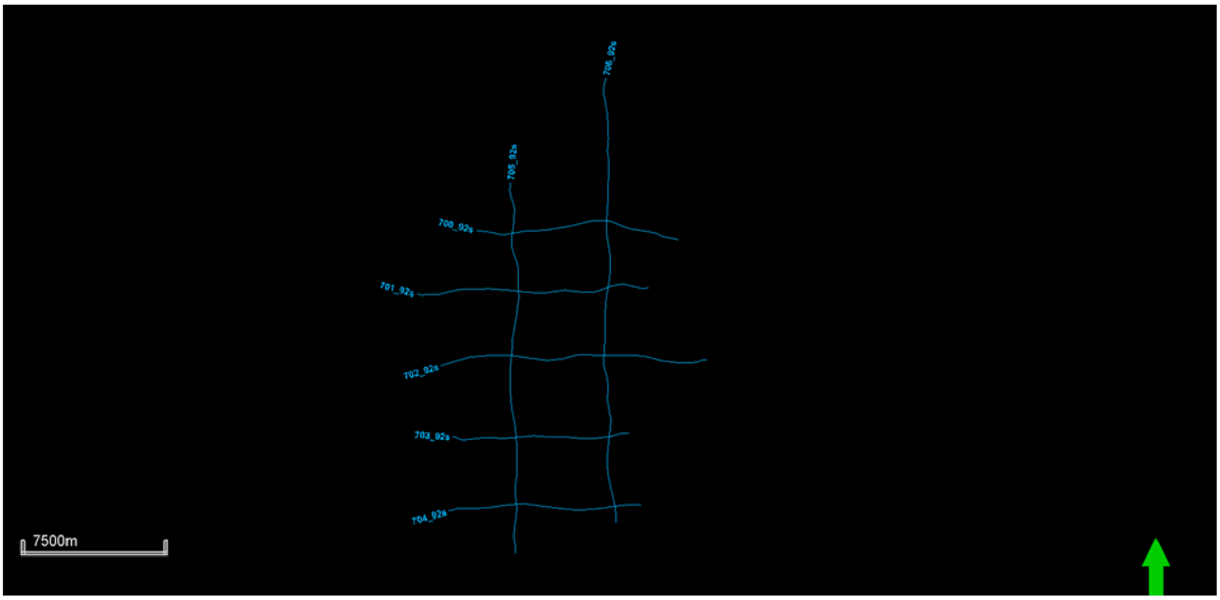


Figure 36 Base map of studies seismic sections.

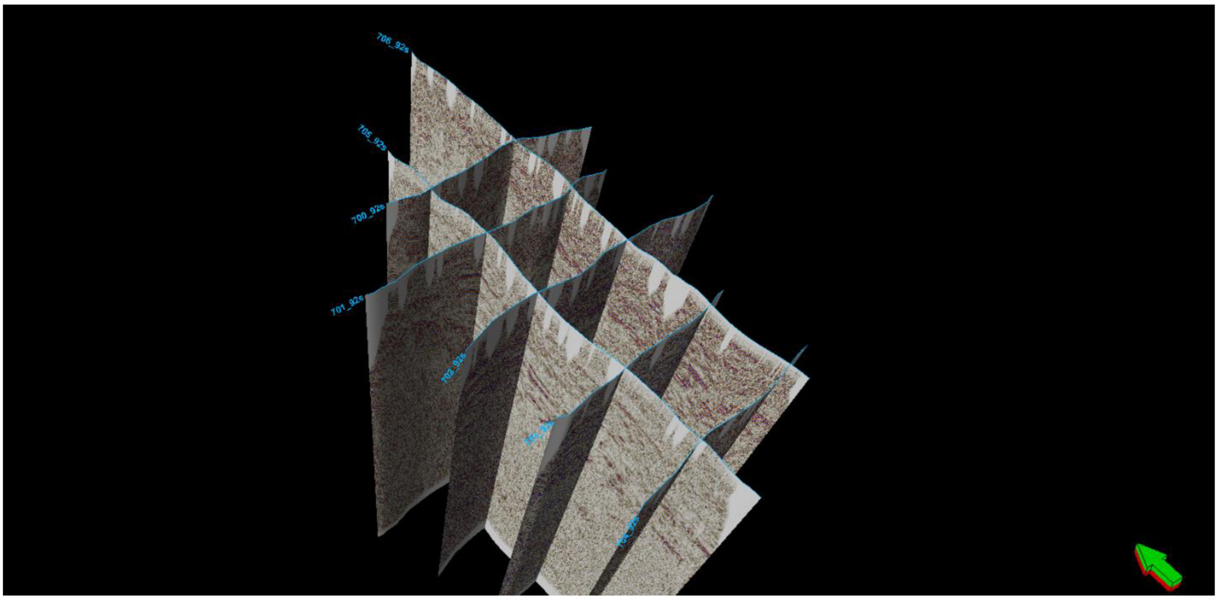


Figure 37 3D view of seismic sections in the Kosice depression.

Seismic section 706:

The section has 4 units (A1 - 4) based on their seismic properties. Each unit has a different depth. In unit A1 we can see the structure layers extend from north to south, and approximately in the middle we can see a normal fault resulting in downshift in the right. At the end of the section we have again a normal fault deforming the reflectors of the seismic.

The first unit (A1) has two different layers. The upper layer has low amplitude, and high frequency, and the layer below has high amplitude with the same frequency.

The Unit A2 has low amplitude and high frequency reflectors. The reflectors have a transparent image.

The Unit A3 has relatively high amplitude and high frequency reflectors.

The last unit (Unit A4) has a different frequency and amplitude than the previous units it has a high frequency and amplitude reflectors, which are more transparent in their lower part

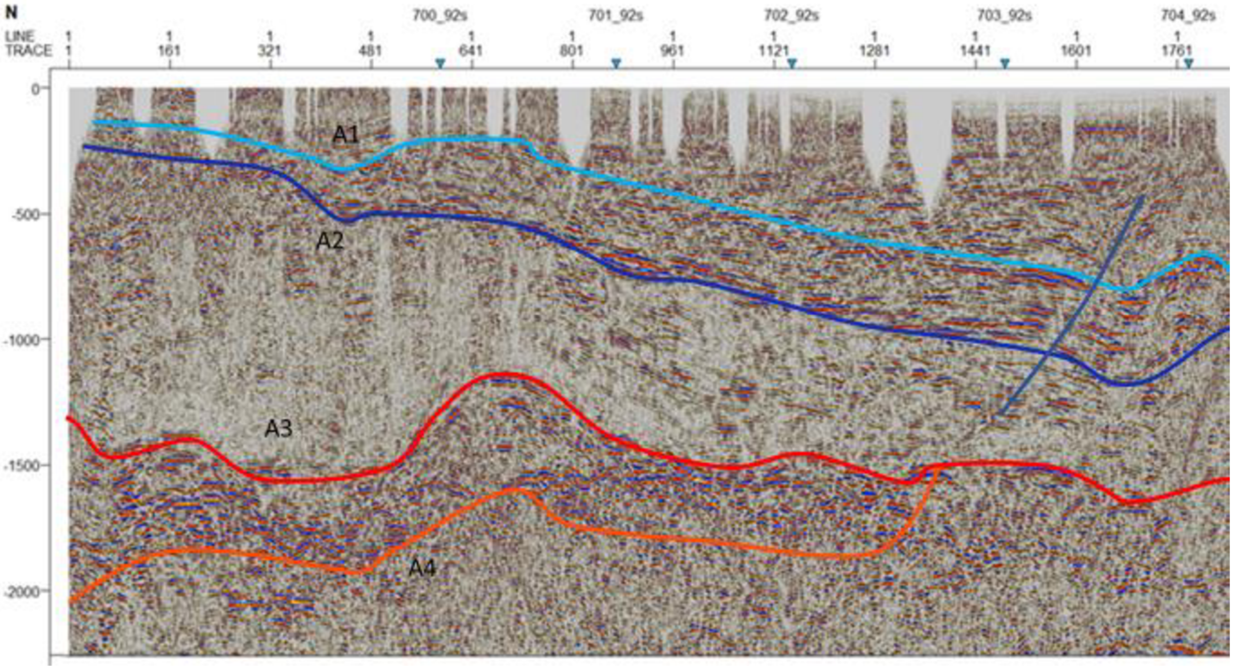


Figure 38 Seismic section 706

Seismic section 705:

The seismic section 705 has north-south trend. Based on the seismic properties, we divided 5 seismic units in the section. The reflectors are deformed by 3 normal faults (see Fig. 35).

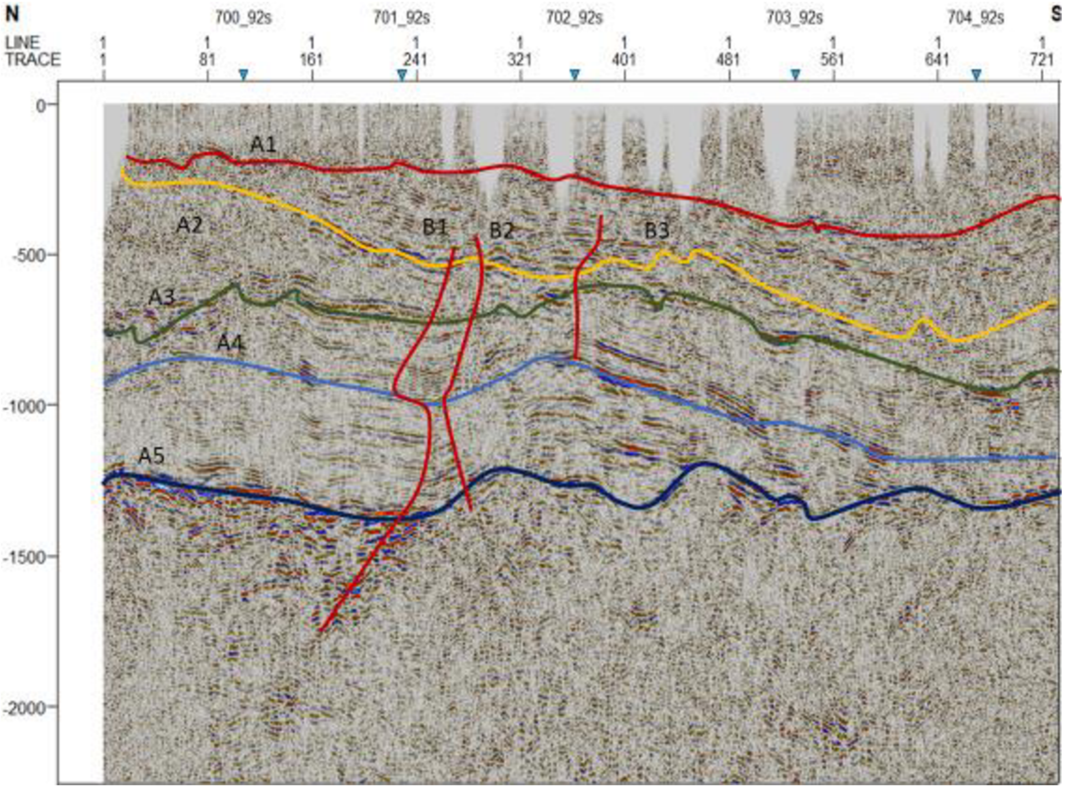


Figure 39 Seismic section 705.

Unit A1 is characterized by transparent reflectors with low amplitude and high frequency. The reflectors are discontinuous.

Unit A2 has two layers the upper part and the lower part. The upper layer has low amplitude and low frequncy in the begining. However, in the middel the fequncy , amplitude and the reflectors are continuity. The lower layer of this unit has higher frequncy and amplitude.

Unit A3 has ahigh amplitute, and frequency and has a continuous reflector like the previous unit.

Unit A4 has low amplitude with low frequncy in some places it has discontinuous and continuous reflectors

Unit A5 has two different boundarieslayer the upper layer, and thelower layer. the upper layer has either low frequncy, oramplitude, and the reflector is discontinue. However, the lower layer has high amplitude, and frequency and the reflector are continuous.

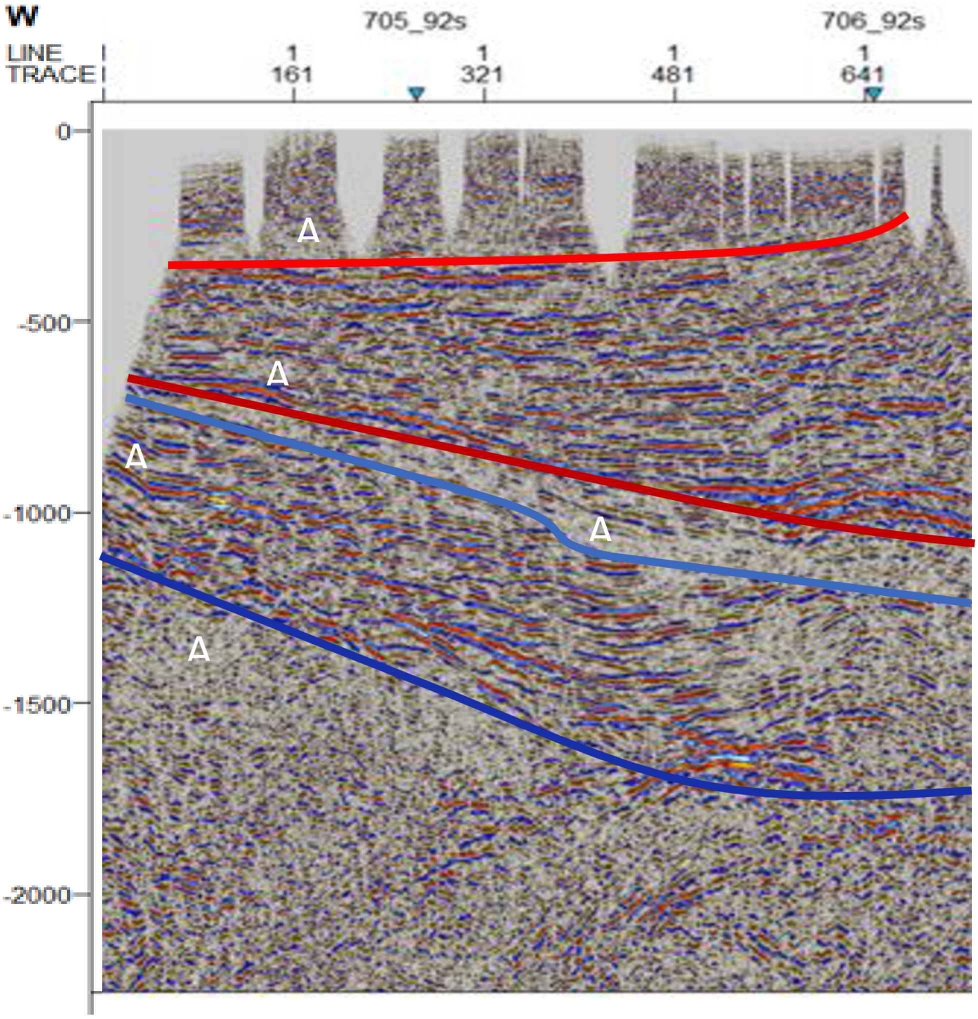


Figure 40 Seismic section 704.

Seismic section 704:

Seismic section 704 is oriented from east to west. It contains 5 seismic units A1-5. The reflectors are deformed by 3 normal faults.

Unit A1 is characterized by transparent reflectors with low amplitude and high frequency. The reflectors are discontinuous.

Unit A2 has either high amplitude or frequency and like its obvious reflector are continues

Unit A3 this unit has different features than the previous unit low amplitude, andlow ,frequency and the reflector is discontinued.

Unit A4 contains two parts the first part (beginning) has high amplitude,and frequency y, and the reflector are continuous. The second part (last) part has low frequncy, and amplitude, and the reflector are discontinued.

Unit A5 has high amplitude and low frequncy. The refletor is discontionus opposite than the privous unit.

The interpreted seismic section shows that the physical/lithological properties of the sediments vary. Generally, they comprise 4 – 5 units with different seismic properties suggesting different lithology (petrophysical parameters, Fig. 37). This knowledge provides animportant tool for characterizing the sedimentary fill of the basin from the point of view of potential reservoir rocks.

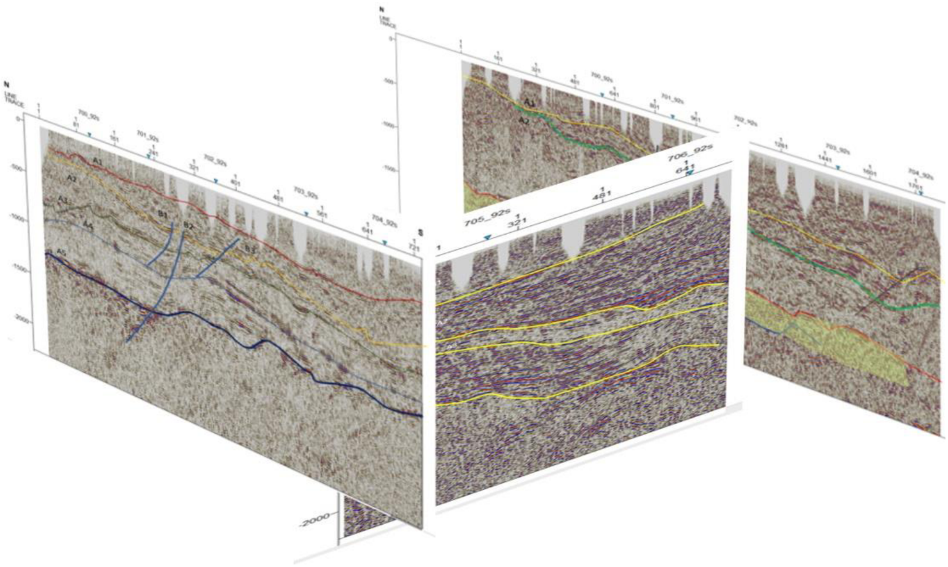


Figure 41 Spatial view on interpreted seismic sections 706, 705 and 704.

Conclusion

Seismic exploration technology belongs to the most important exploration methods used in the oil industry all over the world. The principle of reflection seismic was born in Oklahoma in 1921 and since then, it served in finding thousands of hydrocarbon reservoirs rocks worldwide.

The principle of seismic technology lies in emitting seismic waves subsurface and recording their arrival on the surface after reflection or refraction on seismic boundaries. Seismic waves are energy waves that pass through the earth's crust and are reflected or refracted by various layers of rock or other subsurface components. Energy sources (such as dynamite or a specialized air pistol) are employed in the seismic survey to create seismic waves that are transmitted into the earth. Geophones are sensors placed on the earth's surface to detect seismic waves traveling through the subsurface. Geophone data is utilized to provide a detailed depiction of the underlying layers and structures.

The seismic technology can be divided according to its principles of refraction and reflection seismic.

Refraction seismic is more widely utilized in whole-earth investigations and may examine subsurface velocity and layer interface structure by examining the initial arrival timings of P-waves (longitudinal waves) at the earth's surface. Seismic refraction is utilized in engineering applications to measure rock competence, depth to bedrock, groundwater exploration, crustal structure, and tectonics (Kilner et al., 2005; Asokhai et al., 2008; Varughese et al., 2011; Chiemeke and Aboh, 2012). The seismic refraction technique measures the travel time of seismic waves refracted at the interfaces of different velocity subsurface layers (Ayolabi et al., 2009).

Reflection seismic works on the principle of reflected waves recorded on the surface (either on land by geophones or offshore by hydrophones). The time of the incoming wave may define the depth of the reflection point subsurface. This technology is commonly used in the oil and gas industry to identify potential hydrocarbon reservoirs, but it can also be used for a variety of other purposes such as determining the location of mineral deposits, studying the structure of the Earth's crust, and identifying potential geothermal energy production sites.

According to exploration depth, seismic technology may be divided into shallow and deep seismic. Shallow seismic exploration is a geological and geophysical engineering exploration that detects shallow geological structures. It determines the physical and mechanical parameters of rock and soil by using seismic wave propagation characteristics. Different exploration methods can be utilized to achieve various aims, goals, and geological conditions.

Deep seismic exploration is an exploration commonly used in the oil industry, however, currently, it is also used for the exploration of geothermal sources, mineral deposits, and engineering geology.

Before the seismic picture comes to the seismic interpreter, the raw seismic data (data acquired from seismic shooting) have to be processed. This is a relatively complicated process where demultiplexing, static correction, deconvolution, CDP gathers, and velocity analysis belongs to the most important ones.

The processed seismic sections are provided for seismic interpretation. Even if the interpretation is done by sophisticated software today, the role of seismic interpreters in an oil company is immense. The basic approach is an analysis of seismic facies, types of reflection terminations, and the definition of seismic sequences. The obtained knowledge has to be compared with results from other geophysical/geological exploration technologies.

The interpretation of seismic sections from the Kosice Depression serves as an example of seismic interpretation. Based on the seismic facies, I was able to recognize several units in each section pointing to different lithologies of sedimentary fill.

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